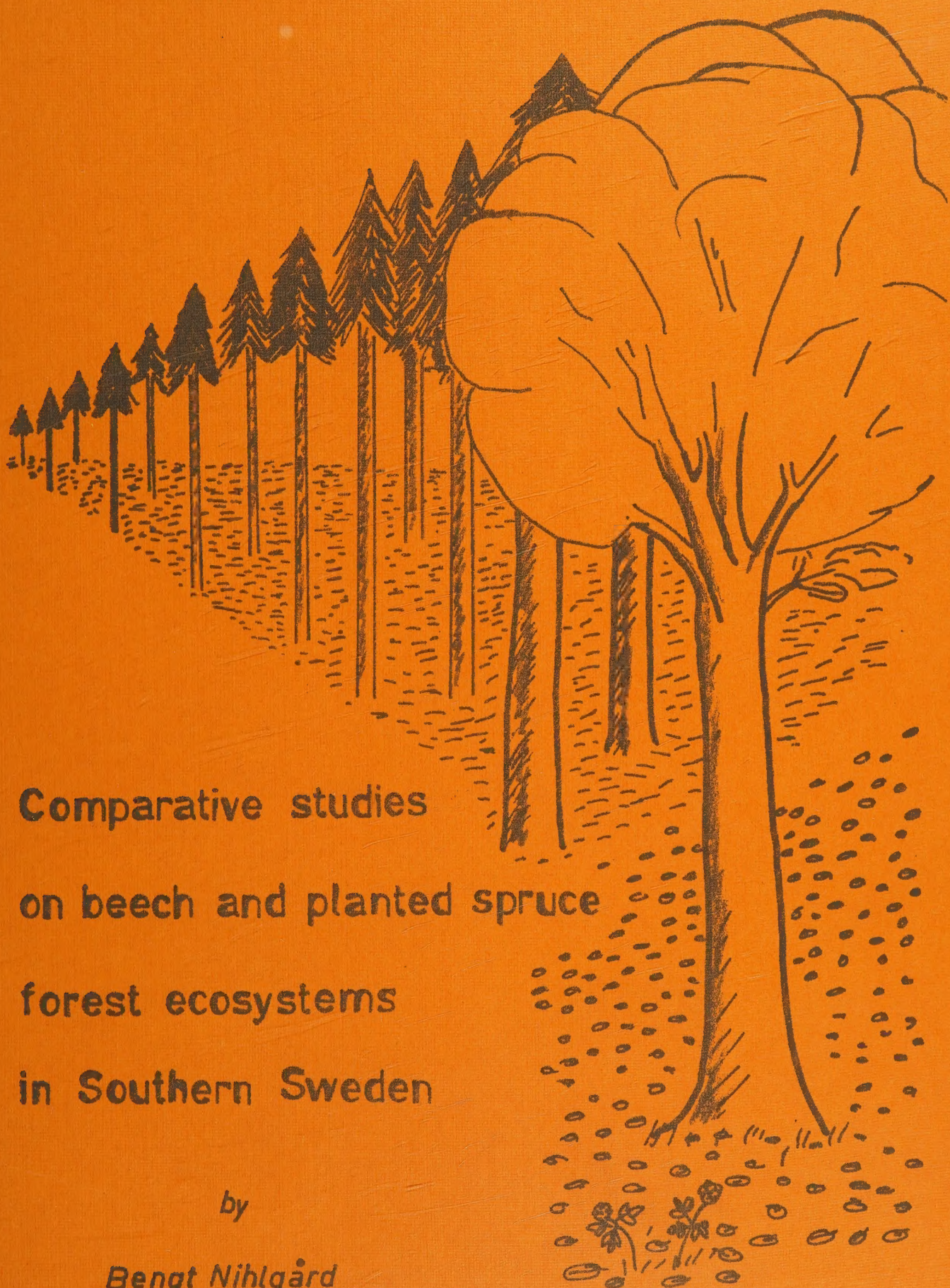


Rund 1970



Comparative studies
on beech and planted spruce
forest ecosystems
in Southern Sweden

by

Bengt Nihlgård

COMPARATIVE STUDIES ON BEECH AND PLANTED SPRUCE
FOREST ECOSYSTEMS IN SOUTHERN SWEDEN

Akademisk Avhandling

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Preface

This mimeographed dissertation is composed of five different papers, three of which are already published in Bot. Notiser (Lund, Sweden) or in press in Oikos (Copenhagen, Denmark), and the other two are in manuscripts. Accordingly the papers can be read separately. Their connection is the comparison between beech and planted spruce forests, mainly carried out in Kongalund, a special area situated in northwestern Scania in Southern Sweden.

The first paper is the result of vegetation and soil investigations in several planted spruce localities. The aim with these studies was primarily to select suitable double-localities with beech and planted spruce forests situated side by side, but secondly also the different vegetation types of the spruce forests demanded for a survey.

The second, the third and the fifth papers deal with ecosystem studies from Kongalund only, and describe the microclimate, the precipitation and the biomass and production respectively. The fourth paper is concentrated on pedological parameters, and besides Kongalund also some other double-localities are included.

The work has been performed during 1966 - 1970 at the Department of Plant Ecology, University of Lund, Sweden. The director Prof. Nils Malmer and Dr. Folke Andersson, Dr. Åke Persson and several other colleagues have in different ways given guidance in my ecological education and scientific work.

I. INTRODUCTION

Beech forests are in Sweden restricted to the southern parts. During the last decades planted spruce forests have replaced beechforests in several areas, and an intensive discussion has arisen between those who want to keep the beech forest area intact and those who want to exploit the economic advances of this substitution. The main purpose of these investigations has been to give, as objectively as possible, some ecological aspects on the difference between beech and planted spruce forests in Scania, and to find out to what extent these differences are due to changes ever since plantation of spruce was performed. This has earlier been treated by especially German and Danish scientists from a pedological or a forestry production point of view. The outstanding question has been if the production of spruce will decrease when planted for several generations on soils formerly covered with beech forests. As yet a decrease in production has not been proved, but nor has the opposite, a continuous high productivity without decrease, been sufficiently proved. Today, most production estimates are inherent in errors of at least 5-10 %. Consequently nobody has been able to detect a production decrease of this order, as there are very few localities, at least in south Sweden, where for certain more than one spruce forest generation has grown.

In the following papers no investigation on this subject is performed. Instead, one special area is selected for comparative ecosystem studies especially directed towards those parameters effecting the soil, e.g. microclimate, precipitation, litterfall, production. Some other localities, with a well known background, are used to detect soil differences between beech and spruce forests, which probably are explained as changes after the spruce was planted on the former beech forest soil. Furthermore a great number of localities with planted spruce forests south of the natural border of spruce in Sweden were used to get a survey of vegetation and soil types of these forests.

II. VEGETATION

Vegetation Types of Planted Spruce Forests in Scania, Southern Sweden

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ABSTRACT

NIELGÅRD, B.: Vegetation Types of Planted Spruce Forests in Scania, Southern Sweden. — Bot. Notiser 123: 310—337, Lund.

Vegetation analyses and soil investigations from 87 localities with planted spruce forest, situated south of the natural border area for *Picea abies* in Scania, have been performed. Most of the stands are old with a well developed ground vegetation, some are young, and some are situated side by side with beech forests. In this way a picture of the different vegetation types, of the development of the vegetation in young and dense spruce plantations and of the floristic changes when beech forests are replaced by spruce is obtained.

Five different vegetation types, separated by different dominating species, are discussed from an ecological point of view, considering in particular, the soil and light conditions. Rough estimations of the productivity of the tree layer are also discussed.

The main species dominating in the vegetation types are: *Dicranum majus*, *D. scoparium*, *D. undulatum*, *Hypnum cupressiforme*, *Plagiothecium* spp., *Pleurozium schreberi*, *Deschampsia flexuosa*, *Oxalis acetosella*, *Dryopteris austriaca*, *Rubus idaeus*, *Sorbus aucuparia*, *Sambucus nigra* and *S. racemosa*.

INTRODUCTION

The southern boundary of the natural distribution of spruce (*Picea abies*) in Sweden, passes through the north part of Scania (Fig. 1). According to pollen analytic investigations (FRIES 1965) this border area has existed for about 1500 years. However, during the last 100 years spruce has also been planted outside its natural borders in the southern deciduous forest region, which belongs to the Nemoral zone (SJÖRS 1965). The plantations have been performed either on formerly grazed heathlands and arable land or replacing beech forests. Owing

to the relatively low financial potential of beech forests and grazing pastures, the spruce plantations have increased during recent decades and it seems probable that in the near future spruce forests will prevail in the deciduous region also.

Having in view a clarification of the vegetation types and the floristic changes which we can expect to find to an ever increasing extent in step with the increasing area of planted spruce forests, the present studies have been made in the southern deciduous forest region of Scania during the years 1966—1969.

INVESTIGATION METHODS

A great number of planted spruce forests south of the natural border of *Picea abies* in Scania have been investigated. The sites chosen for analysis were situated over the whole area (Fig. 1), representing all the different vegetation types obtainable. The stands were 20—85 years old and thus information on the succession of vegetation with age and thinnings was also obtained. The vegetation of the stands was delimited by analysing one large square only, about 2000 m², at each locality. Only homogeneous areas representative of the forests were chosen and investigated, thereby avoiding boundary vegetation.

In order to demonstrate the floristic differences that develop when spruce is planted on former beech forest areas, some localities with both beech and adjacent old spruce forests were analysed. The selection of these double localities was governed by two criteria:

1. The two stands should lie side by side on as flat ground as possible; if situated on a slope the inclination should be uniform.
2. It should be proved, by speaking to the landowner or by studying old land-surveying maps, that beech forest once preceded the planted spruce forest.

On the double localities the stands have been delimited by the choice of two large squares, each 1000—2500 m², which have been placed as near each other as possible, in practice at a distance of 30—50 m. In this way the primary differences of the mineral soil composition between the stands ought to be small. Areas with boundary vegetation, and in the spruce forest areas with beech litter were avoided as far as possible.

The vegetation analysis comprised investigations of the tree, shrub, field, and bottom layers inside the large square.

The tree layer was investigated on the following data:

1. Stand density was determined in the spruce forests by counting numbers of trees inside five squares of 100 m². In the beech forests all trees inside the large square were counted.
2. Cover of the tree crowns was estimated as a percentage of the area of the large square.

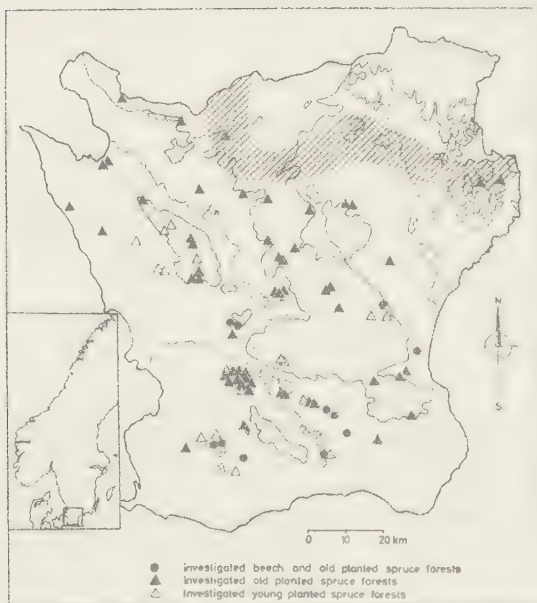


Fig. 1. Map of Scania in Southern Sweden, showing the situation of the investigated localities. The southern border area of the natural distribution of spruce is marked with hatched lines (after HESSELMANN & SCHOTTE 1906). Areas situated more than 100 metres above sea level are dotted. Map of Scandinavia inserted.

3. Age of the trees was determined by boring at breast height in a typical tree with an increment borer. This was possible in the spruce forests where the trees were of the same age. In the beech forest the trees were unevenaged and then the average age was estimated from random borings, and using information obtained from other localities.

4. Measurements of height of the trees and tree crowns were performed using a Blume-Leiss instrument. To obtain average values some typical, subjectively chosen trees were measured from each stand.

5. Average values of diameter of the trees were obtained after measuring ten trees from each stand.

The shrub layer. The cover of the shrub layer was estimated as a percentage of the large square. *Rubus idaeus* was not included.

The field and bottom layers (=the groundlayer) were analysed by placing ten small squares each of 16 m², in a fixed pattern, in order to get a uniform distribution inside the large square. The species inside the small squares were noted and their cover, according to the five-degree scale of HULT—SERNANDER—DU RIETZ, was estimated. Species in the large square, which were not represented in the small squares, were afterwards added to the list and are marked with + in the tables. Bryophytes and lichens on stones or stumps were not included in the analysis.

In the vegetation survey tables the small square frequency (F) and the characteristic degree of cover (C) are given as FC . F denotes the number of small squares in which the species occur calculated as a percentage of the

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total number of small squares, C is an average value of the degree of cover. At its calculation the degrees of cover for each small square are first transformed to mean absolute values of the area covered and then the average of these is retransformed to degree of cover (cf. PERSSON 1961). In Table 1 and Fig. 2 the cover of the vegetation in m^2/m^2 is given. This has been calculated from the units in the HULT—SERNANDER—DU RIETZ scale. Using a small square of $16 m^2$ the following means are valid:

$$1=0.5 m^2, 2=1.5 m^2, 3=3.0 m^2, 4=6.0 m^2 \text{ and } 5=12.0 m^2.$$

The total small square area analysed at each locality is $160 m^2$. By summing the plant cover of every species in the ten small squares this value is often exceeded, which obviously is natural; firstly because both the field and bottom layers are summed, and secondly because there is a natural stratification in several layers even in the field layer. The calculation certainly gives very rough values but these are useful in comparisons and in illustrating the development of the vegetation in planted spruce forests.

The nomenclature for phanerogams and ferns follows WEIMARCK (1963), bryophytes ARNELL (1956), NYHOLM (1954—1965) and JENSEN (1939).

It has not been possible to separate *Dryopteris assimilis* (NANNFELDT 1966) from *D. austriaca*. Both species appear in the investigated forests.

Besides the vegetation analyses investigations on the soil type were performed. One profile of 50—100 cm depth was dug inside each large square. — The validity of this profile was checked with smaller pits over the whole square. — In particular the thicknesses of the different upper horizons, the soil structure and texture were noted. Soil samples for determination of pH were taken in the mor or mull horizon (F/H or A_1), in the horizon just below the mor or mull (A_2 or B_1) and in the B/C-horizon usually at a depth of about 50 cm. pH was determined on duplicated fresh soil samples both in extracts of water and of 0.2 M KCl. The volume proportion soil: solution was 1:2 and the extraction time one hour.

THE DEVELOPMENT OF THE VEGETATION IN SPRUCE PLANTATIONS

The development of the vegetation in spruce forests is earlier treated inter alia by OTT (1966) who studied the effects of thinnings, RHEINHEIMER (1959) and SCHLÜTER (1966) who studied the light and the vegetation in glades. The above authors found that small differences in light could cause great differences in vegetation. RHEINHEIMER (1957) reports that in planted spruce forests near Hamburg, three species were commonly occurring, viz. *Plagiothecium curvifolium*, *Lophocolea heterophylla*, and *Lepidozia reptans*. BECHER (1963) has followed the disappearance of the ground vegetation in small spruce plantation squares and noticed that almost every one of the former beech forest species disappeared. THILL (in NOIRFALISE 1964) reports

Table 1. Vegetation survey table showing the immigration of species in the bottom and field layers of young planted spruce forests in Scania. The stands are arranged according to increasing cover of the vegetation. Species dominating in old spruce forests are underlined. (juv) = juvenile plants. *Plagiothecium* spp. includes *P. curvifolium*, *P. denticulatum* and *P. succulentum*. *Dryopteris* spp. (juv) includes *D. spinulosa* and *D. austriaca*. *Galeopsis* spp. includes *G. bifida* and *G. tetrahit*. *Sambucus* spp. includes *S. nigra* and *S. racemosa*. *Quercus* spp. includes *Q. petraea* and *Q. robur*.

Spruce forest stand No.	51	41	52	9	20	11	6	49	23	21	16	17	1	2	13	47	46
Cover of the vegetation, m ² /m ²	0.03	0.05	0.06	0.10	0.11	0.13	0.14	0.15	0.17	0.18	0.19	0.21	0.23	0.24	0.26	0.27	
Cover of the tree crowns, %	95	100	93	90	80	60	85	90	85	80	65	65	65	90	80	80	
Number of trees/100 m ²	16	42	24	28	11	12	8	32	9	12	13	12	13	15	8	12	
Age at breast height, years	34	20	25	26	35	32	40	25	48	47	40	35	37	36	40	33	53
Diameter at breast height, cm	16	8	12	15	17	20	22	15	25	20	20	19	20	19	18	25	16
Height of the trees, m	10	11	13	13	21	19	19	11	25	24	20	21	21	21	18	20	19
Species	Total number of species																
	2	4	8	12	11	20	15	21	15	19	18	19	18	18	24	18	22
<i>Plagiothecium</i> spp.	50 ¹	60 ¹	70 ¹	70 ¹	30 ¹	30 ¹	100 ¹	30 ¹	30 ¹	20 ¹	100 ¹	90 ¹	100 ¹	100 ¹	90 ¹	80 ¹	100 ¹
<i>Lophocolea heterophylla</i>	50 ¹	70 ¹	40 ¹	50 ¹	100 ¹	60 ¹	100 ¹	70 ¹	100 ¹	90 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹
<i>Polypodium formosum</i>	-	10 ¹	10 ¹	-	-	-	10 ¹	-	-	20 ¹	-	20 ¹	-	-	-	-	-
<i>Mnium affine</i>	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	20 ¹
<i>Mnium hornum</i>	-	20 ¹	20 ¹	-	-	10 ¹	-	-	20 ¹	10 ¹	30 ¹	60 ¹	30 ¹	+	-	-	-
<i>Dicranum scoparium</i>	-	30 ¹	10 ¹	-	-	-	20 ¹	-	10 ¹	20 ¹	-	60 ¹	50 ¹	-	-	-	10 ¹
<i>Pohlia nutans</i>	-	30 ¹	-	-	-	-	-	-	10 ¹	-	-	+	10 ¹	-	-	-	-
<i>Vaccinium myrtillus</i>	-	10 ¹	-	-	-	-	-	-	40 ¹	-	-	-	-	-	-	-	-
<i>Deschampsia flexuosa</i>	-	10 ¹	-	-	-	-	10 ¹	-	-	-	-	50 ¹	-	-	-	50 ¹	80 ¹
<i>Athyrium filix-femina</i> (juv)	-	-	20 ¹	20 ¹	+	+	20 ¹	-	-	-	-	20 ¹	-	10 ¹	+	-	-
<i>Dryopteris</i> spp. (juv)	-	-	20 ¹	50 ¹	20 ¹	40 ¹	20 ¹	40 ¹	40 ¹	50 ¹	40 ¹	50 ¹	40 ¹	50 ¹	40 ¹	-	10 ¹
<i>Rubus idaeus</i> (juv)	-	-	30 ¹	60 ¹	20 ¹	20 ¹	20 ¹	30 ¹	30 ¹	60 ¹	10 ¹	90 ¹	70 ¹	60 ¹	60 ¹	90 ¹	90 ¹
<i>Oxalis acetosella</i>	-	-	+	10 ¹	10 ¹	40 ¹	-	70 ¹	10 ¹	60 ¹	50 ¹	30 ¹	100 ¹	-	20 ¹	-	20 ¹
<i>Moerhousia trinervia</i>	-	-	10 ¹	-	10 ¹	-	+	10 ¹	10 ¹	-	-	-	30 ¹	-	-	-	10 ¹
<i>Atrichum undulatum</i>	-	-	10 ¹	-	10 ¹	10 ¹	20 ¹	-	-	-	40 ¹	-	-	-	20 ¹	-	10 ¹
<i>Viola riviniana</i>	-	-	10 ¹	-	-	-	-	-	-	+	-	-	-	-	40 ¹	+	-
<i>Deschampsia caespitosa</i>	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Dicranella heteromalla</i>	-	-	-	10 ¹	10 ¹	50 ¹	10 ¹	-	-	20 ¹	40 ¹	40 ¹	20 ¹	30 ¹	-	-	-
<i>Galeopsis</i> spp. (juv)	-	-	-	40 ¹	-	-	-	40 ¹	10 ¹	70 ¹	20 ¹	-	-	-	70 ¹	-	-
<i>Senecio sylvaticus</i>	-	-	-	10 ¹	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-
<i>Corylus avellana</i> (juv)	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Chamaenerion angustifolium</i> (juv)	-	-	-	+	10 ¹	-	20 ¹	10 ¹	20 ¹	+	-	20 ¹	+	50 ¹	60 ¹	-	-
<i>Urtica dioica</i>	-	-	-	10 ¹	-	10 ¹	-	-	10 ¹	-	-	20 ¹	-	-	-	-	-
<i>Sambucus</i> spp. (juv)	-	-	-	-	10 ¹	-	30 ¹	-	-	+	-	20 ¹	20 ¹	50 ¹	80 ¹	-	-
<i>Quercus</i> spp. (juv)	-	-	-	-	10 ¹	-	-	-	-	-	-	20 ¹	20 ¹	20 ¹	20 ¹	-	-
<i>Dryopteris filix-mas</i>	-	-	-	-	10 ¹	-	-	-	-	-	10 ¹	-	-	+	10 ¹	-	-
<i>Poa nemoralis</i>	-	-	-	-	-	-	+	-	-	+	10 ¹	-	-	-	80 ¹	-	-
<i>Mercurialis perennis</i>	-	-	-	-	10 ¹	-	-	-	-	+	-	-	-	-	-	-	-
<i>Schrophularia nodosa</i>	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	30 ¹	-	-
<i>Impatiens noli-tangere</i>	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	-	-	-
<i>Hypericum</i> sp. (juv)	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	-	-	-
<i>Picea abies</i> (juv)	-	-	-	-	30 ¹	-	-	-	-	-	-	-	80 ¹	-	-	-	-
<i>Galium saxatile</i>	-	-	-	-	-	10 ¹	-	-	-	10 ¹	-	10 ¹	+	-	90 ¹	40 ¹	-
<i>Hypnum cupressiforme</i>	-	-	-	-	20 ¹	-	-	-	-	+	100 ¹	20 ¹	-	-	30 ¹	30 ¹	-
<i>Betula verrucosa</i> (juv)	-	-	-	-	20 ¹	-	-	-	10 ¹	-	-	-	-	-	-	-	-
<i>Anemone nemorosa</i>	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	-	-	-
<i>Galium odoratum</i>	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
<i>Sorbus aucuparia</i> (juv)	-	-	-	-	-	-	10 ¹	90 ¹	30 ¹	50 ¹	-	90 ¹	10 ¹	30 ¹	100 ¹	-	-
<i>Carex pilulifera</i>	-	-	-	-	-	-	+	10 ¹	10 ¹	-	-	+	-	-	-	-	-
<i>Taraxacum vulgare</i>	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	+	10 ¹
<i>Eurozium schouleri</i>	-	-	-	-	-	-	40 ¹	-	-	-	-	-	-	-	-	-	-
<i>Veronica officinalis</i>	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	-
<i>Eurynehmum stokesii</i>	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-	-
<i>Maianthemum bifolium</i>	-	-	-	-	-	-	-	40 ¹	+	10 ¹	-	+	-	-	10 ¹	-	-
<i>Convallaria majalis</i>	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	10 ¹	-	-
<i>Milium effusum</i>	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-
<i>Ribes</i> sp. (juv)	-	-	-	-	-	-	-	+	-	-	-	-	-	-	10 ¹	-	20 ¹
<i>Trientalis europaea</i>	-	-	-	-	-	-	-	-	30 ¹	-	-	-	-	-	-	-	-
<i>Stellaria media</i>	-	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-
<i>Urtica dioica</i> (juv)	-	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-
<i>Plagiothecium undulatum</i>	-	-	-	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-
<i>Brachythecium reflexum</i>	-	-	-	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-
<i>Rhytidiadelphus loreus</i>	-	-	-	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-
<i>Lactuca muralis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Prunus exelsior</i> (juv)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30 ¹	-	20 ¹
<i>Circaea lutetiana</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 ¹	-	-
<i>Geranium robertianum</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 ¹	-	+
<i>Dryopteris austriaca</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 ¹	10 ¹

that in the Ardennes the planted spruce forests were almost lacking vegetation until 40—50 years of age when they were thinned out.

At the age of about ten or fifteen years the spruce plantation has

grown to such an extent that insufficient light reaches the field and bottom layers, thereby causing their gradual disappearance. The ground is then covered by spruce needles. Usually there will be nothing left of the old ground vegetation, and the species that occur after the first thinnings can be regarded as newly spread plants. It is at this stage of development that this investigation starts.

Table 1 shows a number of vegetation analyses done in dense spruce plantations, where the field and bottom layers cover less than one quarter of the investigation area. Each column corresponds to one site (situation see Fig. 1).

The age at breast height varies from 20 to 50 years, the number of trees/100 m² is 8—42 and the cover of the tree crowns varies from 80 to 100 per cent. All the species of the ground layer are found as scattered individuals; many only as small plants showing evidence of lack of light. Even in the densest stands it is possible to find a small liverwort, *Lophocolea heterophylla*, and a *Plagiothecium* species, usually *P. curvifolium* or *P. denticulatum*. These species occur in almost every stand at all stages of maturity (cf. Table 2 A). Other species appearing at an early stage and found in almost every stand are *Dryopteris* spp. (juv), *Rubus idaeus* (juv), *Oxalis acetosella*, *Chamaenerion angustifolium* (juv) and *Sorbus aucuparia* (juv).

Polytrichum formosum, *Mnium hornum*, *Moehringia trinervia*, *Atrichum undulatum*, *Dicranella heteromalla*, and *Sambucus* can also be regarded as shade tolerant species, while e.g. *Deschampsia flexuosa*, although it can be found as small straws in glades in dense spruce forests, is most prominent in older and lighter stands.

The development of the vegetation is dependent on the cover of the tree crowns and density and these properties are usually correlated with the age of the stand. In Fig. 2 the age of the stands at breast height is correlated with the cover of the vegetation. Most of the old stands in Table 2 are also included. It is obvious that it is not until the stand is 45—50 years of age that the bottom, field, and shrub layers are of real importance and cover the whole ground area. At this age the cover of the tree crowns is usually 70—80 % and the number of trees per 100 m² is 5—8. In such a stand a mature vegetation type slowly appears.

It is possible to summarize the development of the ground vegetation in a planted spruce forest by dividing it into four developmental stages:

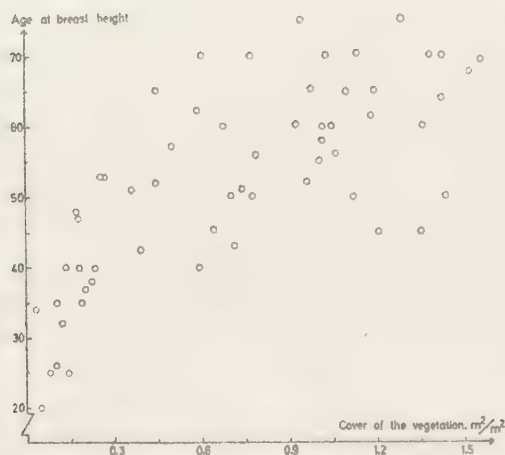


Fig. 2. Diagram showing the relation between the age of the trees at breast height and the cover of the bottom, field and shrub layers.

1. The depletion stage, lasting from the time of planting to about 15 years of age. During this stage the initial ground vegetation disappears.

2. The bare ground stage, at 15—30 years of age, is described as the time when ground vegetation is almost lacking.

3. The immigration stage, at 30—60 years of age, is the time when ordinary spruce forest species appear.

4. The mature stage appears from about 60 years of age and typical vegetation types can be distinguished.

The rotation of spruce in Southern Sweden is 60—70 years and thus the fourth stage is often short or not fully realised.

VEGETATION TYPES IN OLD PLANTED SPRUCE FORESTS

Of the 84 localities investigated 67 were used for describing the vegetation types in old planted spruce forests (situation, see Fig. 1). The condition governing the selection of these sites was that the vegetation of the bottom, field, and shrub layers together should cover at least 50 % of the area. However, a few forests, which from a forestry point of view could be regarded as mature and ready for total cutting, were also included.

a. The Vegetation

When comparing the vegetation from the 67 localities it was found that many of them were very similar, at least with regard to domi-

nating species. On this criterion they were grouped in 27 different columns (Table 2). In this survey table the frequency values are rounded off to the nearest five.

In Table 2 A high frequency species, i.e. species with a frequency of > 50 % in at least one column, are gathered. A continuous change in the vegetation from the left to the right is seen, with very close relationships between adjacent columns. However, it is possible to differentiate into groups or types if dominating species are taken into account. Thus five main types have been established.

I. The moss dominated types are found mainly in the northern part of the investigated area or on the Scanian ridges, where stony and sandy moraines poor in nutrients, prevail (cf. WEIMARCK 1950). The main dominating species are *Dicranum majus*, *D. scoparium*, *D. undulatum*, *Hypnum cupressiforme*, *Plagiothecium curvifolium*, *P. denticulatum*, *P. undulatum*, and *Pleurozium schreberi* (Fig. 3). The vegetation dominated by *Dicranum majus* and *Plagiothecium* species is found in more shady forests and probably on more moist soils, than those dominated by *Dicranum undulatum*, *D. scoparium*, *Hypnum cupressiforme*, and *Pleurozium schreberi*. Though somewhat indifferent the latter species are found e.g. on dry sandy soils in the Vomb area in the centre of south Scania. Most of the high frequency species of the moss dominated forests also occur in other types, but *Dicranum majus*, *D. undulatum*, *Ptilium crista-castrensis*, and *Hylocomium splendens* have their main distribution in type I. *Deschampsia flexuosa* sometimes becomes a co-dominating species, particularly on dry soils and in sun-exposed stands. This vegetation is closely related to the following type.

II. In the *Deschampsia flexuosa* types *Deschampsia flexuosa* is the main species. This type is found on apparently dry localities on stony moraine with a thick mor horizon. It is a vegetation also found at the edges of young or middle-aged planted forests, where the light conditions are sufficient. In consequence it occurs only in sufficiently thinned forests where the cover of the tree crowns is as little as 50—60 %. In the most heavily thinned forests the ground vegetation has the character of edge vegetation and *Deschampsia flexuosa* can reach fertility which normally is rare in enclosed stands. Type II can be divided into two subtypes: II A, where in particular, *Dicranum scoparium* is co-dominating and II B, where *Deschampsia* is dominating alone. The *Deschampsia* — moss subtype may be regarded as a successional stage where *Deschampsia flexuosa* is increasing with increased

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VEGETATION TYPES OF PLANTED SPRUCE FORESTS IN SCANIA 319

Species	Vegetation types	I	II A	II B	III A	III B	III C	IV A	IV B	IV C	V A	V B
B. Low frequency species												
Field and bottom layers (FC)												
<i>Bertholaphia barbata</i>		40'										
<i>Cnidaria</i> sp.		10'	10'									
<i>Polytrichum juniperinum</i>			5'									
<i>Rhodobryum roseum</i>			5'									
<i>Autacanthium anaglynum</i>			5'									
<i>Monotropa hypopitys</i>			5'									
<i>Pleurozium aquilinum</i>			5'									
<i>Rhytidadelphus loreus</i>		40'				40'	30'					
<i>Rhytidadelphus squarrosus</i>		15'				10'	10'					
<i>Polygonatum multiflorum</i>		6'		6'	15'	10'	5'	5'	30'		5'	
<i>Rumex acetosella</i>		+	5'	5'			5'	5'				
<i>Stellaria holostea</i>		+					+					
<i>Lophoceros bidentata</i>		20'	15'	15'	60'		10'	5'	5'			
<i>Rhamnus frangula</i> (juv)			5'	30'	10'		25'	35'			10'	
<i>Lycopodium annalinum</i>			5'			5'	30'	5'				
<i>Silphium</i> sp.						5'	10'					
<i>Helianthemum sylvaticum</i>			5'			40'	20'					
<i>Metastachyum pratense</i>			35'				5'					
<i>Dicranella heteromalla</i>			25'	10'	6'	20'	10'	5'	20'	10'	10'	20'
<i>Galeopsis tetralix</i>			25'	10'	20'		20'		5'	25'		
<i>Polypodium vulgare</i>			10'	+	20'	10'	10'	5'		5'		
<i>Solidago virgaurea</i>												
<i>Scleropodium purum</i>				10'					5'	5'		
<i>Convallaria majalis</i>				5'	5'				5'	5'		
<i>Potentilla erecta</i>				+					5'	5'		
<i>Anemone nemorosa</i>						40'			10'	10'	10'	
<i>Loiseleuria dryopteris</i>					+				10'	10'	10'	
<i>Galeopsis bifida</i>					5'	25'	20'		5'	5'		10'
<i>Stellaria media</i>					5'			5'	5'	5'	10'	
<i>Brachythecium curtum</i>					30'		20'		15'	15'	5'	
<i>Veronica officinalis</i>					5'				5'	5'	10'	
<i>Fagus sylvatica</i> (juv)					+		30'		5'	5'	15'	+
<i>Deschampsia caespitosa</i>						5'		5'	5'	10'		
<i>Hieracium vulgatum</i>									5'	5'		
<i>Athyrium filix-terre</i>							5'		5'	10'	10'	20'
<i>Eurynchium stokesii</i>							5'		5'			
<i>Pragmites asplenoides</i>							5'		5'			
<i>Prunus</i> sp. (juv)									5'	5'	+	
<i>Viola riviniana</i>								15'	10'	15'		
<i>Hypnum impanens</i>								10'				
<i>Salix</i> sp. (juv)									5'	5'	5'	
<i>Calyptogeomys neesiana</i>									5'	5'		
<i>Lepidozia reptans</i>									5'	5'		
<i>Corylus avellana</i> (juv)									5'	5'		
<i>Campanula rotundifolia</i>									5'	5'		
<i>Dryopteris filix-mas</i>									5'	5'	10'	
<i>Phlegmaria polypodioides</i>									5'	5'		
<i>Ranunculus repens</i>									5'	5'	30'	
<i>Epilobium montanum</i>									5'	5'	20'	
<i>Brachythecium reflexum</i>									5'	5'	10'	
<i>Fragaria vesca</i>									5'	5'	10'	
<i>Geranium robertianum</i>									5'	5'	25'	
<i>Isotrichum myurum</i>									5'	5'	10'	
<i>Dactylis glom.ssp. eschers.</i>									5'	5'		
<i>Festuca gigantea</i>									5'	5'		
<i>Rubus fruticosus</i>									5'	5'		
<i>Schrophularia nodosa</i>									5'	5'		
<i>Galium odoratum</i>									5'	5'		
<i>Pulmonaria officinalis</i>									5'	5'	20'	
<i>Melandrium rubrum</i>									5'	5'	+	
<i>Campanula latifolia</i>									5'	5'	30'	
<i>Actaea spicata</i>									5'	5'	40'	
<i>Dentaria bulbifera</i>									5'	5'	10'	
<i>Eurynchium striatum</i>									5'	5'		
<i>Adoxa moschatellina</i>									5'	5'	20'	
<i>Tussilago farfara</i>									5'	5'	15'	
<i>Lathyrus montanus</i>									5'	5'	10'	
Shrub layer (<5%)												
<i>Rhamnus frangula</i>					45'	45'	45'	45'			45'	
<i>Fagus sylvatica</i>						45'	45'	45'				
<i>Quercus petraea</i>						45'	45'	45'				
<i>Corylus avellana</i>							45'	45'				
<i>Betula verrucosa</i>								45'				
<i>Ribes rubrum</i>									45'	45'	45'	
<i>Ulmus glabra</i>									45'	45'	45'	
<i>Viburnum opulus</i>									45'	45'	45'	
<i>Lonicera xylosteum</i>									45'	45'	45'	
<i>Ribes alpinum</i>									45'	45'	45'	
<i>Euonymus europaeus</i>									45'	45'	45'	



Figs. 3 and 4.

thinnings and better light conditions and grows over a primary moss carpet. In some forests, however, the moss carpet is more or less absent and then *Deschampsia flexuosa* starts as small green plots over the whole area as in the first column of II B and remains as the only dominating species in later stages.

III. The *Deschampsia* — *Oxalis* types embrace some slightly different subtypes, A—C. They have in common dominating *Deschampsia flexuosa* and *Oxalis acetosella*. Apparently, they always occur on more moist soils than type II. This statement is established in Fig. 5. At the top of the slope (plot no. 3) the forest was slightly more thinned and consequently lighter than in plots no. 1 and no. 2, where the light conditions were estimated to be uniform. Plot no. 3 shows a pure *Deschampsia flexuosa* community where *Deschampsia* covers almost the whole area. In plot no. 2 the soil conditions were similar with an obvious mor horizon, but due to lower light intensities a *Deschampsia flexuosa* layer was not yet fully developed. However, in plot no. 1 situated at the bottom of the slope and facing north, the groundwater was wetting the soil surface and the humus layer was intermediate between mor and mull. The vegetation was an *Oxalis acetosella* variant, probably developing towards a *Deschampsia* — *Oxalis* — *Dryopteris* subtype (III B).

As the light conditions were similar in plots 1 and 2, this also illustrates, besides the floristic changes, a better development of the ground vegetation with improved soil conditions.

In subtype III A *Deschampsia flexuosa* and *Oxalis acetosella* are the only dominating species. *Oxalis* can be regarded as the primary species. *Deschampsia* is the secondary species, and has expanded over *Oxalis* when light intensities have increased. However, this vegetation will hardly become a pure *Deschampsia flexuosa* community, since after thinning shrubs such as *Sorbus aucuparia* and *Sambucus racemosa*, will appear. The shading influence of the shrubs will retain a *Deschampsia* — *Oxalis* community.

Fig. 3. A moss dominated vegetation with *Dicranum majus*, *Hypnum cupressiforme* and *Pleurozium schreberi* as the most prominent species. NE Vedby. —

Photo: B. N. Sept. 1969.

Fig. 4. A subtype of the *Deschampsia* — *Oxalis* vegetation dominated by *Dryopteris austriaca*, *Oxalis acetosella*, *Deschampsia flexuosa*, *Polytrichum formosum*, *Mnium hornum*, *Luzula pilosa*, and *Vaccinium myrtillus*. Shrubs of *Sorbus aucuparia* are prominent. Sjunnerup. — Photo: B. N. Sept. 1969.

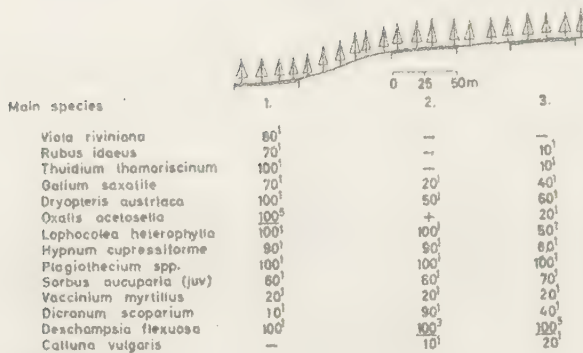


Fig. 5. The main results of vegetation analyses from a transect of a slope in the Crown forest of Dalby.

Fig 5

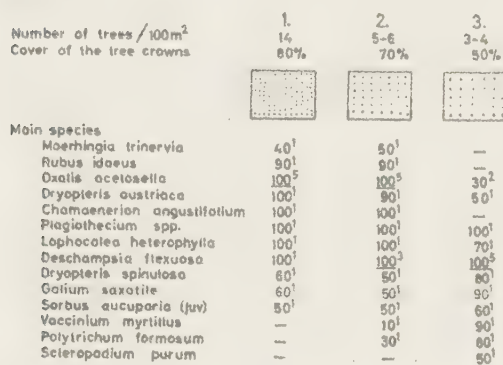


Fig. 6. Vegetation analyses from different thinned stands, situated side by side on the same soil in the Crown forest of Dalby. Stand number 1 and 3 belong to some experimental plots managed by the Forest Research Institute of Sweden.

Fig.6

On more moist soils, *Deschampsia flexuosa* is superseded by tall ferns, especially *Dryopteris austriaca*, and by *Rubus idaeus* (III B and III C). The *Dryopteris* variant is often found on stony moraine in slopes or hollows with a good supply of ground water (Fig. 4). More moist conditions are also indicated by species such as *Deschampsia caespitosa*, *Athyrium filix-femina* and *Plagiochila asplenioides*. Also, shrubs of *Sorbus aucuparia* and *Sambucus racemosa* can grow tall. The subtype III C with both *Deschampsia*, *Oxalis*, and *Rubus idaeus* can be regarded as an intermediate stage between III and IV.

IV. The *Rubus* — *Oxalis* types can be divided into three subtypes, A—C. In these *Deschampsia flexuosa* is rare or scattered and *Oxalis acetosella* and *Rubus idaeus* are usually co-dominating. In IV A *Oxalis* dominates alone, covering more than 50 % of the area. However, this community is not a fully developed vegetation type but must be re-

garded as an immigration stage in a vegetation succession of planted spruce forests on moist soils with good humification properties. *Oxalis acetosella* is a very shade tolerant species and the community is often found in very dense, middle-aged (about 45 years old) spruce forests. With increased thinnings the vegetation does not have to develop into a *Rubus* — *Oxalis* type, but might as well become a *Deschampsia* — *Oxalis* variant of type III. Such a succession is clearly demonstrated in some thinning plots for forestry production measurements in the Crown forest of Dalby (Fig. 6). The three stands in this example are situated side by side on the same stony moraine and are equal in age. In the densest stand, where no thinning has been done, *Oxalis acetosella* is dominating alone, while in the heaviest thinned plot, no. 3, *Deschampsia flexuosa* is the most important species. Plot no. 2 is intermediate.

In subtype IV B the vegetation has developed into a *Rubus idaeus* — *Oxalis acetosella* community. This is, in fact, not a clearing vegetation as it is found in relatively close stands, where it covers the whole area (Fig. 7). As with *Deschampsia flexuosa*, *Rubus idaeus* also rarely flowers inside the forests. This happens only in glades or clearings.

Subtype IV B always grows on soils with an astonishingly good humus condition, and podsolizing effects are almost lacking. It is frequently found on slopes where it has been planted on former meadows. It also occurs on level ground, especially when the spruce forest is planted as the first generation on former beech forest areas (cf. p. 333). Then some typical beech forest species, e.g. *Stellaria nemorum* ssp. *glochidosperma*, *Lamium galeobdolon*, *Dactylis glomerata* ssp. *aschersoniana*, *Festuca gigantea*, and *Galium odoratum* can also occur in the spruce forest.

Subtype IV C is a spruce forest vegetation found in one locality only. The spruce is planted on a former beech forest area, probably having a *Mercurialis perennis* community. The soil is extremely rich in lime, has a high pH value (cf. Fig. 11) and a good supply of water. *Lamium galeobdolon*, *Mercurialis perennis*, *Oxalis acetosella*, and *Rubus idaeus* are co-dominants in the field layer. Several other species indicating a good supply of water and mineral nutrients are found, e.g. *Actaea spicata*, *Campanula latifolia*, *Dentaria bulbifera*, *Melandrium rubrum*, and *Pulmonaria officinalis*.

V. The *Sambucus* — *Oxalis* type is separated because of a great dominance (> 50 %) of 1—3 m high *Sambucus* shrubs (Fig. 8). In the field layer *Oxalis acetosella* and sometimes *Dryopteris austriaca* are



Figs. 7 and 8.

dominating, while the bottom layer is poorly developed. This vegetation is found on similar soil types to the *Rubus* — *Oxalis* types, i.e. soils with a good water supply and probably a good nutrient status, especially concerning nitrate and ammonia. Fertilizing experiments on small plots made by BECHER (1963) indicate that *Sambucus racemosa*, as well as *Rubus idaeus* and *Chamaenerion angustifolium*, is favoured by a good nitrogen supply. The *Sambucus* type was never found on poor stony moraine with a mor humus.

An extreme variant is subtype V B with dominating *Sambucus* shrubs almost lacking field and bottom layers. This variant is usually found in isolated plantations on former arable land. The lack of ordinary forest vegetation can be explained by absence of suitable spreading agents. *Sambucus racemosa* and *S. nigra* are spread mainly by birds.

There is an ecologic difference between the occurrence of *Sambucus racemosa* and *S. nigra*. Although they sometimes grow together, *Sambucus nigra* seems to have high demands of water and nutrients and prefers silt or clay rich soils with mull, while *Sambucus racemosa* can also grow on sandy soils where real mull structures are lacking. However the humus layer is very porous and loose, which is a common feature of all the *Sambucus* vegetation types.

A porous humus layer with mull structures can be created artificially by liming or by fertilizing with nitrogen (cf. the nitrogen experiments by BECHER 1963). The most striking effect of liming is the marked increase of the shrub layer (Fig. 9). Shrubs of *Sambucus racemosa* about 2 m tall have grown up in the limed plots. Moreover an increase of *Rubus idaeus* and *Oxalis acetosella* is noticeable. A great number of new species have invaded the limed ground, e.g. *Adoxa moschatellina*, *Lactuca muralis*, *Ranunculus repens*, *Viola riviniana*. Other species have disappeared or decreased, e.g. *Dicranum scoparium*, *Hypnum cupressiforme*, *Deschampsia flexuosa*, *Galium saxatile*.

Besides this qualitative floristic difference it can be noted that the cover of the vegetation is doubled in the limed stands. This demonstrates that it is not only low light intensities that prevent the development of the vegetation, but also the humus condition (cf. NIHLGÅRD 1969).

Fig. 7. Vegetation type dominated by *Rubus idaeus* and *Oxalis acetosella*. N. Rörum.
— Photo: B. N. Sept. 1969.

Fig. 8. Vegetation type with 1—3 m high *Sambucus nigra* and *Sambucus racemosa* in the shrub layer. *Oxalis acetosella* is dominating the field layer. S. Djurup. —
Photo: B. N. Sept. 1969.

Main species	Unlimed plots		Limed plots	
<i>Dicranum scoparium</i>	70 ¹	60 ¹	—	—
<i>Gallium saxatile</i>	60 ¹	50 ¹	—	—
<i>Hypnum cupressiforme</i>	100 ²	70 ¹	50 ¹	—
<i>Deschampsia flexuosa</i>	80 ²	80 ¹	40 ¹	—
<i>Dryopteris austriaca</i>	100 ²	100 ²	100 ¹	100 ²
<i>Vaccinium myrtillus</i>	60 ¹	80 ¹	40 ¹	20 ¹
<i>Plagiothecium</i> spp.	100 ¹	100 ¹	100 ¹	100 ¹
<i>Oxalis acetosella</i>	80 ¹	100 ¹	100 ¹	100 ¹
<i>Rubus idaeus</i>	100 ¹	70 ¹	100 ¹	100 ¹
<i>Moerhingia trinervia</i>	30 ¹	—	90 ¹	100 ¹
<i>Lactuca muralis</i>	—	—	100 ¹	100 ¹
<i>Adoxa moschatellina</i>	—	—	20 ¹	20 ¹
<i>Ranunculus repens</i>	—	—	40 ¹	20 ¹
<i>Viola riviniana</i>	—	—	30 ¹	30 ¹
Shrubs (%)				
<i>Sorbus aucuparia</i>	10%	< 5%	< 5%	< 5%
<i>Sambucus racemosa</i>	< 5%	< 5%	50%	50%
Cover of the vegetation, m ² /m ²	Σ 0.63	Σ 0.80	Σ 1.41	Σ 1.48
Humus conditions	Mor, 3-5 cm	Mor, 5-7 cm	Mult, 5-10 cm	Mult, 4-8 cm
pH in 0.2 M KCl	2.90	3.00	6.85	6.50
" " water	3.85	3.85	7.25	6.80

Fig. 9. Vegetation analyses showing the effects of liming on spruce forest vegetation. The sites belong to production experiments of the Forest Research Institute of Sweden in the Crown forest of Dalby.

b. Comparisons with Other Spruce Forest Vegetation

It is difficult to compare the described types of vegetation with the vegetation in natural spruce forests in Scandinavia or Central Europe. In natural stands the vegetation and soil have developed into ecosystems in equilibrium or with changes occurring very slowly. In the planted spruce forests, however, the thinnings have a great influence upon the vegetation and when planted on soils formerly used for other purposes, the soil conditions are in no way in ecologic equilibrium with the influence from spruce. Swift changes concerning the soil conditions can be observed (cf. GENSSLER 1959, NOIRFALISE 1964). These changes must be considered to proceed slowly throughout several generations of planted spruce forests and certainly will also influence the development of the bottom, field and shrub layers. It is probable that the vegetation types of these planted spruce forests in future generations will develop into vegetation types more like those of the naturally occurring forests.

It can be noted that real wet growing vegetation types are lacking in the planted Scanian forest. This mainly depends on the fact that plantation has not been done on such areas, and when wet vegetation does occur, the areas are too small to be included in my investigation as a different vegetation type.

The moss dominated forests of type I are those which are most closely related to the moss rich *Vaccinium myrtillus* or *Vaccinium vitis-idaea* forest types, which are common further north in Scandinavia and in Central Europe (CAJANDER 1909, 1922, HARTMANN 1932, REINHOLD 1939, MALMSTRÖM 1949, TAMM & HOLMEN 1961, ARNBORG 1964). However, the *Vaccinium* species are rarely dominating in the planted

Scanian spruce forest, probably due to the low light intensities. It is also notable that for example *Hylocomium splendens*, a moss species commonly found in natural spruce forests both in Scandinavia and Central Europe, plays a very small role in the Scanian forests.

Similar moss vegetation in planted spruce forests is described by KØIE (1938) from Denmark, MALMSTRÖM (1937) from Halland, RHEINHEIMER (1957) from the surroundings of Hamburg, and ELLENBERG (1968) from Ostfriesland.

Deschampsia flexuosa types (II) are reported by ALMQVIST (1929) from Uppland and is also found in investigations from Denmark (KØIE 1938) and from BRD (GENSSLER 1959). LINDQVIST (1932) mentioned a *Deschampsia flexuosa* community in the planted Scanian spruce forest.

The vegetation types III—V are all to be regarded as herb-forests with low or tall herbs (cf. TAMM & HOLMEN 1961).

With different composition of the non-dominating species the *Deschampsia* — *Oxalis* types (III) are found in several variants especially in vegetation analyses from Central Europe (CAJANDER 1909, HARTMANN 1932, REINHOLD 1939). KØIE (1938) distinguished a special *Deschampsia* — *Oxalis* sociation in Danish conifer plantations.

The *Dryopteris austriaca* subtype (III B) is reported as a fern spruce forest by ELLENBERG (1968) from Ostfriesland. Fern types with several *Dryopteris* species, particularly *Dryopteris filix-mas*, are common in Scandinavian spruce forests (cf. ALMQVIST 1929, ARNBORG 1964).

Rubus — *Oxalis* types (IV) are described both from Germany by CAJANDER (1909) and in planted forests from Denmark (KØIE 1938) as preferring soils with a mull or mor/mull structure.

The pure *Oxalis acetosella* subtype (IV A), considered as a primary stage of the types III—IV, is reported from Central Europe (CAJANDER 1909, LANGER 1960), from Denmark (KØIE 1938), and from Central Sweden (ALMQVIST 1929, HOLMEN 1964). HOLMEN found this community, including e.g. *Lophocolea heterophylla*, in dense spruce forest stands on drained peat land. LINDQVIST (1932) mentioned an *Oxalis* community which developed towards a *Deschampsia flexuosa* or a *Rubus idaeus* community.

The *Mercurialis* subtype (IV C) is reported both from natural spruce forests in Sweden (HEDBERG 1949), from the Alps (LANGER 1960) and from planted European forests (recognizable in investigations from AICHINGER 1952).

The *Sambucus* — *Oxalis* types (V) are perhaps more connected to Southern Sweden and to Central Europe than to the remaining part of Scandinavia. *Sambucus* shrubs in spruce forests, especially when planted on former arable land, can certainly be found inside the whole distribution area of *Sambucus racemosa* and *S. nigra*.

c. Soil Profiles and pH-values

Before discussing the results (Fig. 10) some remarks must be made on the terminology used, which essentially follows LINNEMARK (1960).

A podzol (P) is characterized as a soil with an obvious mor horizon containing different decomposition stages (F+H layers) and with a grey or ash-white leaching horizon (A_2), above a brown or red-brown precipitation horizon (B_2).

A podzoloid (Pd) is a soil with a mor horizon but with indistinct A_2 and B_2 horizons. Though it is possible to distinguish an A_2 -horizon this is not ash-white but greyish-black from a high humus content. They often occur in spruce forests planted on former grasslands or heaths, or on soils with relatively good water conditions. The podzoloids can be regarded as degenerative soil types when occurring under spruce. Depending on the thickness of the A_2 horizon the podzols (P) and the podzoloids (Pd) can be divided into three groups: strong (SP, SPd) with $A_2 > 10$ cm, medium (MP, MPd) where A_2 is 10—4 cm and weak (WP, WPd) with $A_2 < 4$ cm. Often it is difficult to distinguish between podzoloids and weak podzols as there may be a successive transition from a grey colour immediately below the mor, to a more greyish-black colour further down, indicating a development into a humus podzol. However, these transitional stages have been classified as podzoloids.

Among the brown earths LINNEMARK distinguishes between oligotrophic brown earths (OBr) with the thickness of the mull horizon < 4 cm, mesotrophic brown earths (MBr) with 4—10 cm mull and eutrophic brown earths (EBr) with the mull horizon more than 10 cm thick. The mull horizon is denoted A_1 . The term brown earth is used in a wide sense, and comprises brown and acid brown forest soils.

Strong podzols occur mainly in the moss rich forests (I) and in the *Deschampsia flexuosa* types (II) (Fig. 10 A). Of the *Deschampsia* — *Oxalis* variants (III) most profiles can be characterized as podzoloids but strong podzols and oligotrophic brown earths also appear. The *Rubus* — *Oxalis* type (IV) is most often found on podzoloids or brown earths, while the *Sambucus*-type (V) in its extreme form occurs only on different brown earths.

The mor or mull horizon under the litter layer acts very selectively on species and must be regarded as the most important soil horizon for the development of the shrub and ground vegetation. Obviously mor is the dominating soil surface horizon in the vegetation types I—III

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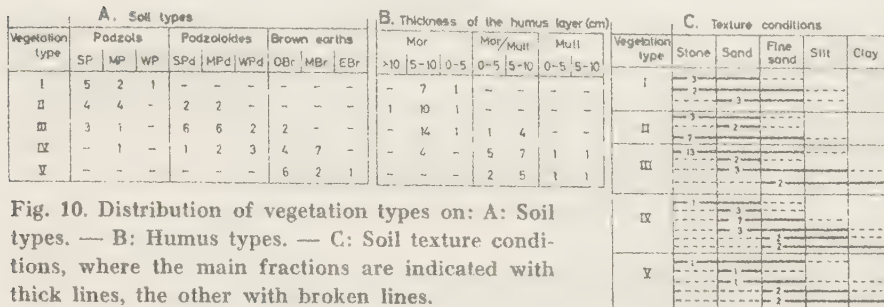


Fig. 10. Distribution of vegetation types on: A: Soil types. — B: Humus types. — C: Soil texture conditions, where the main fractions are indicated with thick lines, the other with broken lines.

(Fig. 10 B). However, in type III it is also possible to find many intermediate stages between mor and mull, designated mor/mull. — A real mor horizon can be characterized as a purely organic horizon, while a mull is an intimate mixture of both organic and inorganic compounds. In the mor/mull horizon one can find a very morlike structure above or sometimes slightly mixed with a more mull-like structure. — In the vegetation types IV and V usually this mor/mull horizon is found, but obvious mull horizons also appear.

The investigation of the texture conditions (Fig. 10 C) is founded solely on observations from the field and deals only with the main fractions of the soil. There is no great difference between the vegetation types, but on the whole stony and sandy soils are dominating in sites with the vegetation types I—III, while more silt and clay rich soils are found in sites with types IV and V. The fine sand and silt fractions are especially important for maintaining a good water supply.

For the correct interpretation of the pH-measurements (Fig. 11) the principal difference between a pH measured in extracts of distilled water and potassium chloride, must be realized. In water extract a pH essentially gives the acidity of the easily moving soil water, while in the potassium chloride extract the pH is an expression of the total exchangeable fraction of acid ions, since the potassium ions are exchanged e.g. for the hydronium ions. With increasing content of acid ions on the colloids the pH in potassium chloride extracts is lowered and will diverge more and more from those in water extracts. As can be seen from Fig. 11 this difference is distinctly marked in the mor or mull horizons, and especially in the vegetation types I—III where real mor horizons are dominating. The difference is at least one pH-unit. In the B/C horizons the differences between the measurements obtained from the two different methods are much less, only about 0.3—0.4 pH

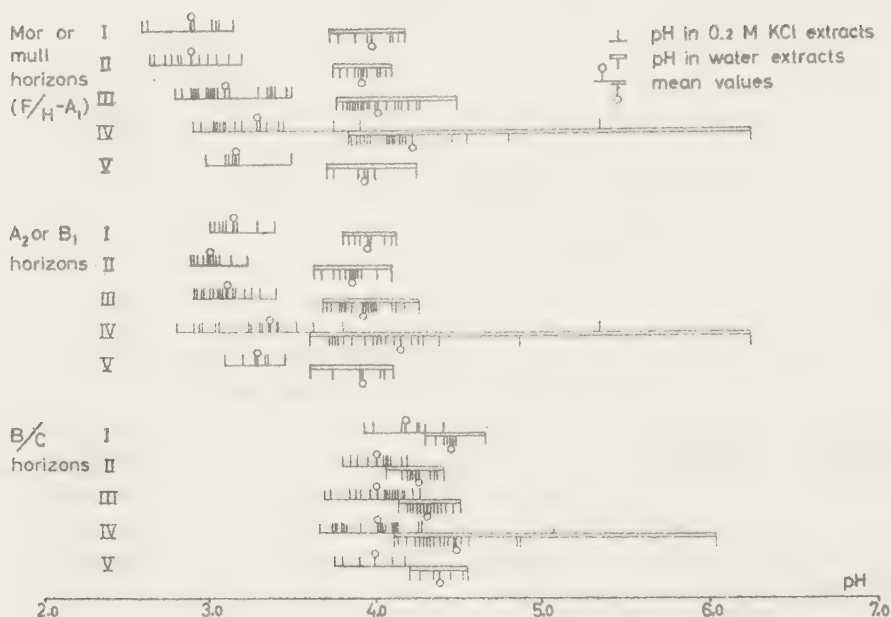


Fig. 11. pH-values on soil samples from three horizons of the different vegetation types.

units. Moreover, all these pH values are markedly higher than those of the soil surface. The A₂—B₁ horizon values have an intermediate position.

Significant differences concerning the pH values between the vegetation types are found neither in the water extracts from any horizon, nor in the potassium chloride extracts from A₂ or B/C horizons. It is only in the mor or mull horizon that differences are notable in the latter extracts. Thus the soils of types I and II are more acid than the other. Type IV shows a large variation, reflecting the great variation in vegetation. Values from the limed plots described on p. 326 are not included in type V.

The unimportant differences of pH in water extracts suggest that other ecological conditions, e.g. the supply of water and available nutrients, are of greater importance for the floristic differentiation of the vegetation.

The pH values of the water extracts are in good agreement with those of KØIE (1938) of corresponding plant communities.

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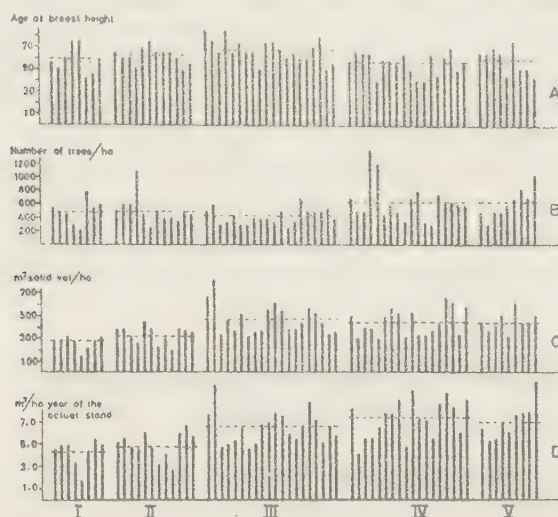


Fig. 12. Bar graphs on tree layer data of the investigated old planted spruce forests. Average values for the vegetation types are indicated by horizontal dashed lines. — A: The age of the trees at breast height. — B: The stand density expressed as trees per hectare. — C: The wood content (=the growing stock volume), expressed as cubic metre solid volume over bark per hectare. The values are based upon the estimations of tree height, tree diameter and number of trees/ha and are calculated from the volume tables of NÄSLUND & HAGBERG (1950). — D: The production calculated as the mean production of wood per hectare and year of the present remaining stand, i.e. earlier thinnings are overlooked.

d. Notes on the Tree Layer

In Fig. 12 A—D some notes on the tree layer of the investigated stands are given. The age at breast height (Fig. 12 A) varies from 40 to 85 years, but the average age of the different vegetation types differs only slightly. The number of trees per hectare (Fig. 12 B) varies from 250 to 1400. The average values are lowest in types I—III and highest in IV and V. The absolute values of the growing stock volume indicated in Fig. 12 C are founded on estimations, and must be very rough. *t*-tests on the given values in Fig. 12 C, reveal that solid volume over bark in types I and II differ with a probability of 99 or 99.9 % from the other types. A difference in the solid volume could of course be due to different thinning procedures but the average values of the tree density do not advocate this, as in fact types I and II have a slightly higher tree density than e.g. III, but still a lower solid volume.

In calculating the production of solid volume per hectare and year, the values of the growing stock volume were divided by an estimation of the total age, obtained after adding six years to the age at breast height of the vegetation types I and II, five years to the others. Also in productivity the vegetation types I and II differed with a probability of 99 or 99.9 % from the remaining types. There is an indication of lower productivity in the *Sambucus* type (V), but this can equally be due to different management of the forests. It is, for instance, impossible to know how much timber has been removed earlier by thinnings.

CHANGES IN VEGETATION WHEN BEECH FORESTS HAVE BEEN REPLACED BY PLANTED SPRUCE FORESTS

The beech forests included in this study (Table 3) represent the most important types viz. the "heath beech forests", on podsolized soils with mor, and the "meadow beech forests" on brown earth with mull (LINDGREN 1968).

The most prominent changes are that species typical for the meadow beech forests decrease while species typical for the heath forests increase in the spruce forests. Thus e.g. *Deschampsia flexuosa* and *Maianthemum bifolium* increase but *Allium ursinum*, *Deschampsia caespitosa*, *Galium odoratum*, *Lamium galeobdolon*, *Mercurialis perennis*, *Stellaria holostea*, *S. nemorum* ssp. *glochidosperma*, and *Viola riviniana* decrease. *Stellaria nemorum* ssp. *glochidosperma*, known as a fairly acidophilic species, manages better in the spruce forest than e.g. *Galium odoratum* or *Lamium galeobdolon*. Among other species, e.g. the nitrophilic species *Rubus idaeus* increases greatly. Also *Oxalis acetosella* is favoured in the spruce forests, but *Anemone nemorosa* decreases. Several other species are favoured and are often found to be frequent in the spruce forests but rarely or never in the beech forests. To these belong most of the species in the second half of Table 3 (p. 333). In particular several mosses and plants such as *Dryopteris austriaca* and *Sambucus racemosa* appear. Similar changes are found by THILL in the Ardennes (in NOIRFALISE 1964). He points out a drift towards a shrub land flora on mor in the planted spruce forests. LOHMEYER (1964), in a report to NOIRFALISE, mentions *Stellaria holostea* as a species that will disappear, *Oxalis acetosella* as one that will remain unchanged, while e.g. *Chamaenerion angustifolium*, *Mnium hornum*, *Moehringia trinervia*, *Rubus idaeus*, and *Sambucus nigra* will increase.

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Table 3. Vegetation survey table showing the vegetation of some beech forests and corresponding spruce forests situated side by side on the same soil. Typical beech forest species are found in the upper half of the table. Below these the high frequency species left from the spruce forest vegetation in Table 2 A are added.

Stand No.	Beech forests											Spruce forests										
	4	19	22	7	8	5	14	16	12	10	15	4	19	22	7	8	5	14	16	12	10	15
Cover of the tree crowns, %	75	70	90	80	80	70	90	70	90	60	90	60	60	60	65	75	65	60	75	60	60	60
Number of trees / 1000 m ²	16	22	25	14	17	11	14	30	21	14	36	70	50	50	50	50	85	65	60	120	80	65
Diameter at breast height, cm	30	32	27	45	35	40	47	40	40	35	30	27	30	30	33	23	35	24	20	25	30	30
Height of the trees, m	23	23	27	29	26	20	31	24	27	27	26	25	30	25	30	28	24	29	24	21	23	27
Species Total number of species	45	27	12	28	30	34	24	15	21	34	30	30	44	22	31	27	25	26	31	20	32	35
<i>Vaccinium myrtillus</i>	-	-	-	-	-	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-	-
<i>Vitis vinifera</i>	100 ¹	-	70 ¹	-	-	-	-	-	-	-	-	20 ¹	-	30 ¹	20 ¹	10 ¹	-	10 ¹	-	-	-	-
<i>Corylus avellana</i>	80 ¹	80 ¹	10 ¹	90 ¹	40 ¹	-	-	-	-	-	-	100 ¹	90 ¹	-	-	20 ¹	-	-	-	-	-	70 ¹
<i>Deschampsia flexuosa</i>	100 ¹	40 ¹	30 ¹	40 ¹	70 ¹	-	-	-	-	-	-	40 ¹	50 ¹	100 ¹	100 ¹	100 ¹	-	60 ¹	90 ¹	-	10 ¹	70 ¹
<i>Luzula pilosa</i>	100 ¹	90 ¹	50 ¹	90 ¹	20 ¹	-	10 ¹	-	-	10 ¹	-	30 ¹	90 ¹	40 ¹	-	50 ¹	-	-	-	-	-	10 ¹
<i>Maianthemum bifidum</i>	60 ¹	0 ¹	70 ¹	10 ¹	-	-	10 ¹	30 ¹	20 ¹	70 ¹	10 ¹	60 ¹	30 ¹	60 ¹	10 ¹	-	10 ¹	50 ¹	90 ¹	50 ¹	-	30 ¹
<i>Oxalis acetosella</i>	70 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹
<i>Anemone nemorosa</i>	10 ¹	100 ¹	100 ¹	10 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	10 ¹	50 ¹	100 ¹	100 ¹	100 ¹	-	10 ¹	30 ¹	40 ¹	+ 10 ¹	-
<i>Poa nemoralis</i>	50 ¹	30 ¹	10 ¹	30 ¹	80 ¹	70 ¹	20 ¹	20 ¹	-	80 ¹	10 ¹	-	80 ¹	100 ¹	100 ¹	100 ¹	-	10 ¹	30 ¹	40 ¹	+ 10 ¹	-
<i>Dryopteris spinulosa</i>	20 ¹	-	-	10 ¹	-	10 ¹	30 ¹	60 ¹	-	60 ¹	-	100 ¹	80 ¹	10 ¹	70 ¹	40 ¹	80 ¹	100 ¹	60 ¹	50 ¹	90 ¹	20 ¹
<i>Milium effusum</i>	-	+	-	-	20 ¹	-	50 ¹	+ 20 ¹	100 ¹	70 ¹	-	-	30 ¹	10 ¹	-	30 ¹	-	20 ¹	80 ¹	-	30 ¹	100 ¹
<i>Dryopteris filix-mas</i>	-	-	-	-	-	-	-	-	-	30 ¹	-	-	-	-	-	-	-	-	-	+	-	-
<i>Rubus idaeus</i>	+ 20 ¹	-	-	30 ¹	40 ¹	-	20 ¹	+ 70 ¹	80 ¹	20 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	90 ¹	60 ¹	100 ¹	100 ¹	70 ¹	100 ¹	100 ¹
<i>Deschampsia caespitosa</i>	40 ¹	10 ¹	-	20 ¹	50 ¹	+ 20 ¹	-	-	60 ¹	10 ¹	-	-	30 ¹	-	-	-	-	20 ¹	-	-	-	50 ¹
<i>Vitis vinifera</i>	-	20 ¹	-	20 ¹	90 ¹	70 ¹	70 ¹	100 ¹	50 ¹	90 ¹	40 ¹	-	-	-	10 ¹	-	-	30 ¹	-	10 ¹	-	-
<i>Stellaria holostea</i>	10 ¹	-	-	70 ¹	10 ¹	+ 40 ¹	-	-	100 ¹	60 ¹	-	-	-	-	+ 60 ¹	-	-	-	-	-	-	-
<i>Malva uniflora</i>	-	20 ¹	-	30 ¹	100 ¹	-	-	-	100 ¹	90 ¹	-	-	-	-	70 ¹	10 ¹	-	-	20 ¹	-	-	10 ¹
<i>Lamium galeobdolon</i>	-	40 ¹	-	-	30 ¹	100 ¹	-	-	-	100 ¹	90 ¹	-	-	-	-	-	-	-	20 ¹	-	-	10 ¹
<i>Galium odoratum</i>	-	-	-	-	30 ¹	100 ¹	30 ¹	-	20 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	-	-	-	-	20 ¹	-	-	10 ¹
<i>Stellaria nemorum ssp. glach</i>	-	-	-	-	-	-	80 ¹	50 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	-	-	-	40 ¹	20 ¹	30 ¹	30 ¹	100 ¹
<i>Urtica dioica</i>	-	-	-	-	10 ¹	-	-	10 ¹	+ 40 ¹	40 ¹	-	-	10 ¹	-	-	-	-	10 ¹	-	-	20 ¹	-
<i>Dactylis glomerata ssp. aschers.</i>	-	-	-	10 ¹	-	-	-	-	+ 90 ¹	30 ¹	-	-	-	-	-	-	-	-	-	-	40 ¹	+
<i>Mercurialis perennis</i>	-	-	-	-	20 ¹	-	-	-	-	20 ¹	-	-	20 ¹	-	-	-	-	-	-	-	-	+
<i>Hordeium europaeum</i>	-	-	-	-	-	-	-	-	-	20 ¹	-	-	20 ¹	-	-	-	-	-	-	-	-	10 ¹
<i>Aegopodium podagraria</i>	-	-	-	-	-	-	-	-	-	30 ¹	-	-	30 ¹	-	-	-	-	-	-	-	-	10 ¹
<i>Allium ursinum</i>	-	-	-	-	-	-	-	-	-	10 ¹	-	-	10 ¹	-	-	-	-	-	-	-	-	-
<i>Pleurozium schreberi</i>	20 ¹	-	-	-	-	-	-	-	-	-	-	-	-	80 ¹	-	-	-	-	-	-	-	-
<i>Quercus spp. (juv)</i>	20 ¹	-	-	-	-	-	-	-	-	-	-	-	10 ¹	20 ¹	-	30 ¹	10 ¹	-	-	20 ¹	20 ¹	10 ¹
<i>Galium saxatile</i>	40 ¹	-	-	-	-	-	-	-	-	-	-	-	-	90 ¹	-	50 ¹	30 ¹	-	20 ¹	-	-	-
<i>Mnium hornum</i>	40 ¹	-	-	10 ¹	10 ¹	-	-	-	-	-	-	-	90 ¹	70 ¹	-	10 ¹	10 ¹	20 ¹	-	-	10 ¹	40 ¹
<i>Sorbus aucuparia (juv)</i>	10 ¹	10 ¹	30 ¹	30 ¹	-	-	-	10 ¹	10 ¹	-	-	-	20 ¹	20 ¹	10 ¹	60 ¹	50 ¹	50 ¹	-	80 ¹	30 ¹	+
<i>Picea abies (juv)</i>	100 ¹	70 ¹	-	60 ¹	10 ¹	-	-	-	-	-	-	-	80 ¹	80 ¹	40 ¹	60 ¹	80 ¹	20 ¹	+ 50 ¹	-	80 ¹	30 ¹
<i>Polia nutans</i>	10 ¹	10 ¹	-	20 ¹	-	-	-	-	-	10 ¹	-	-	50 ¹	50 ¹	-	30 ¹	10 ¹	10 ¹	-	-	-	-
<i>Dicranum scoparium</i>	70 ¹	40 ¹	-	60 ¹	10 ¹	-	-	-	-	-	-	-	90 ¹	90 ¹	50 ¹	30 ¹	10 ¹	10 ¹	-	-	-	-
<i>Polytrichum formosum</i>	90 ¹	30 ¹	10 ¹	-	20 ¹	-	10 ¹	-	+	-	10 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	-	30 ¹	10 ¹	10 ¹
<i>Hypnum cupressiforme</i>	40 ¹	60 ¹	-	60 ¹	-	10 ¹	10 ¹	-	-	-	-	40 ¹	20 ¹	-	10 ¹	80 ¹	10 ¹	30 ¹	-	-	-	-
<i>Plagiothecium spp.</i>	20 ¹	40 ¹	-	40 ¹	20 ¹	40 ¹	-	30 ¹	10 ¹	10 ¹	10 ¹	90 ¹	100 ¹	100 ¹	100 ¹	90 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	90 ¹
<i>Lophocolea heterophylla</i>	20 ¹	-	-	20 ¹	20 ¹	20 ¹	-	30 ¹	10 ¹	10 ¹	-	100 ¹	100 ¹	100 ¹	20 ¹	70 ¹	100 ¹	100 ¹	100 ¹	100 ¹	100 ¹	40 ¹
<i>Lactuca muralis</i>	-	10 ¹	-	-	10 ¹	-	-	-	-	-	-	-	+	-	10 ¹	20 ¹	-	50 ¹	-	20 ¹	80 ¹	40 ¹
<i>Moerhousia trinerve</i>	-	10 ¹	20 ¹	10 ¹	10 ¹	30 ¹	-	10 ¹	-	-	-	10 ¹	10 ¹	10 ¹	40 ¹	80 ¹	-	10 ¹	90 ¹	90 ¹	40 ¹	+
<i>Atrichum undulatum</i>	-	10 ¹	-	-	20 ¹	70 ¹	-	-	-	20 ¹	-	20 ¹	50 ¹	-	20 ¹	-	100 ¹	+ 10 ¹	10 ¹	50 ¹	-	-
<i>Sambucus spp.</i>	-	-	-	-	30 ¹	20 ¹	-	-	-	-	-	-	10 ¹	+	20 ¹	-	100 ¹	10 ¹	10 ¹	10 ¹	10 ¹	10 ¹
<i>Chamaenerion angustifolium</i>	-	-	-	-	-	-	-	-	-	-	-	-	60 ¹	20 ¹	30 ¹	20 ¹	-	80 ¹	40 ¹	50 ¹	+ 100 ¹	50 ¹
<i>Betula spp. (juv)</i>	-	-	-	-	-	-	-	-	-	-	-	-	30 ¹	-	-	30 ¹	-	20 ¹	-	-	-	-
<i>Hylocomium splendens</i>	-	-	-	-	-	-	-	-	-	-	-	-	10 ¹	50 ¹	-	10 ¹	-	-	-	-	-	-
<i>Plagiothecium undulatum</i>	-	-	-	-	-	-	-	-	-	-	-	-	40 ¹	-	-	-	-	-	-	-	-	-
<i>Mnium affine</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	80 ¹	-	10 ¹	-	-	-	40 ¹	10 ¹	-
<i>Dryopteris austriaca</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	20 ¹	-	100 ¹	-	-	-	-	-	-
<i>Calluna vulgaris</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	10 ¹	-	-	-	-	-	-	-	-
<i>Dicranum majus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Ptilium crista-castrensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shrub layer (%)																						
<i>Sambucus racemosa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	50 ¹	-	-	-	-	8 ¹
<i>Sorbus aucuparia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10 ¹

Deschampsia flexuosa, *Galium saxatile* and *Mnium affine* are regarded as new species in the spruce forest.

CONCLUDING REMARKS

The development of the vegetation in planted spruce forests in Scania is strongly dependent on the direct effects of thinnings. The light must be regarded as the limiting growth factor for the bottom field and shrub layers (cf. NIHLGÅRD 1969). The first species to invade the naked forest ground after the first thinnings are very shade tolerant species. Many of them will stay at a germinating stage. With increased thinnings and at 45—50 years of age the light intensities are high enough to permit an active growth of the bottom, field and shrub layers. Species which can withstand or prefer an acid milieu — probably often rich in soluble nitrogen — on a thick layer of spruce needles, are favoured. Certainly the vegetation of the surrounding forests is of importance as a source of immigration.

Most of the mature forest vegetation can be regarded as a mixture of unstable plant communities, but it is possible to establish some types, due to the dominance of species in the bottom, field or shrub layers. Such a "type" of vegetation is usually found in connexion with particular ecological conditions what concerns the soil, soil-water and light. See Fig. 13, which is founded on earlier discussions and thus derives mainly from my own field observations.

Considering the dry—moist gradient the *Deschampsia flexuosa* type and the moss types belong to the driest, though the species have a very wide ecologic range. *Rubus idaeus*, often characterized as a nitrophilic species, is dominating on more moist soils with good humification properties. The *Sambucus* — *Oxalis* type appears on a similar soil type as the *Rubus idaeus* community, but often on soils with a higher content of clay which are slightly wetter. However, the *Sambucus* subtype VB occurs on former cultivated soils which could be fairly dry, but there is still a porous humus layer, apparently with good nitrification and characterized as a mor/mull.

The *Dryopteris austriaca* community is obviously linked to soils which are influenced by high but drainable ground water, and moreover it is found mainly on stony and sandy moraine.

The dark—light gradient especially illustrates that a primary *Oxalis acetosella* vegetation can develop into many of the other separated types. Moreover, this gradient indicates that vegetation occurs and

VEGETATION TYPES OF PLANTED SPRUCE FORESTS IN SCANIA 335

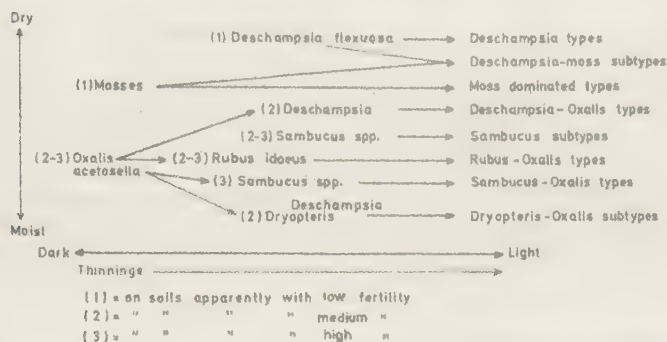


Fig. 13. Schematic ecological interpretation of the vegetation types in planted Scanian spruce forests.

covers larger areas at an earlier stage on soils with good humification properties or with a good water supply, than on drier soils with a mor horizon.

Thus the different vegetation types are linked to certain ecological conditions and these differences obviously also affect the production of the tree layer. It is possible to separate the vegetation types I and II as more low-productive than the others, which show higher and equal production, in spite of apparently better soil conditions in types IV and V compared with type III. This suggests that the optimum cultivating conditions for spruce in Scania have already been reached in type III, and it further suggests that the ground water is the limiting growth factor (cf. TROEDSSON 1955 p. 183). Changes in vegetation when spruce forests have replaced beech forests, indicate that species which can withstand a more acid milieu are favoured.

The studied vegetation types are found in the first generation of planted spruce forests in Scania. It is very probable that with further generations the soil conditions will change in an acidifying and mor developing way, which will favour the development of vegetation types I—III. The *Sambucus* and the *Rubus idaeus* variants, indicating a good nitrification status, are likely to disappear with future generations, as mor formation with a delayed nitrification can be expected.

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III. MICROCLIMATE

The Microclimate in a Beech and a Spruce Forest — a Comparative Study from Kongalund, Scania, Sweden

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ABSTRACT

A comparative climatic study of a 100-years old beech forest and a 55-years old planted spruce forest is reported. The stands are situated side by side with identical soil textural conditions. Results regarding light, temperature, relative humidity and wind velocity are given for three comparable days with clear weather, one from each of spring, summer and late autumn. Moreover, continuous measurements of soil temperature from two horizons are discussed. The greatest differences between the two stands were found in the spring before the time of leafing. Differences in radiation also caused differences in temperature and relative humidity. Thus in the beech forest there was a larger amount of incoming radiation rendering a higher soil temperature and, in the middle of the day, a lower relative humidity. During the summer the differences were small and insignificant with slightly higher soil temperatures in the beech forest. Light is discussed as a limiting factor for the ground vegetation in the spruce forest. Values of incoming radiation energy, estimated from a neighbouring meteorological station, are given. The temperature differences are discussed from an ecological point of view.

INTRODUCTION

The present paper is one part of an investigation with the purpose of elucidating the ecological-pedological changes occurring when spruce is planted on forest ground formerly covered with beech. It does in no way embrace a treatment of all climatic features. It aims mainly to illustrate certain similarities and differences in the climate near the ground which exist between beech and planted spruce forests. It is possible from periodical measurements to discuss some of the effects of the climate on ground and vegetation, without giving absolute values of continuous measurements throughout the whole year.

To some extent similar investigations are found, especially in Central European literature. Works of BURGER (1934 a, b) and COMBE (1957)

may be emphasized. They have more or less directly compared beech and spruce from a forest climatic point of view. In the present paper light, temperature, relative humidity and wind are treated, while the precipitation will be dealt with in a future paper.

DESCRIPTION OF THE AREA

The investigation was carried out in Kongalund, a woodland situated south of the ridge of Söderåsen in the northwestern part of Scania, Sweden (55°59'N, 13°10'E). According to the bedrock map from the Institute of Geology, Lund, the bedrock consists of Cambrian shales and sandstones, which are overlaid by a thick layer of glacial material and moraine with an even distribution of grain sizes. The climate is characterized by a yearly precipitation of 800 mm, a humidity of 270 mm (according to TAMM 1959) and an average temperature for the whole year of 6—7°C (Atlas över Sverige 1953).

Kongalund (Fig. 1) is mainly an old beech forest area but embraces several parts which have been planted with spruce during recent years. As appears from Fig. 1 two sampling areas have been worked with, one in the beech forest and one in the spruce forest, designated A and B respectively. They have been placed as close to each other as possible but yet sufficiently far apart that the reciprocal influence could be neglected. The sampling areas are situated on level ground with identical soil textural conditions.

The beech forest has an average age of 100 years with a tree density of 210 trees/ha. The spruce forest is 55 years old and contains 880 trees/ha. In both stands the tree height ranges from 25—30 m and the canopy cover is 80—90 %. The beech forest has a more or less closed field layer dominated by a *Stellaria nemorum* - *Lamium galeobdolon* community with *Anemone nemorosa* in the vernal aspect. In the spruce forest the field layer is absent except for a few individuals of *Oxalis acetosella* and some small plants of *Dryopteris spinulosa* and *Rubus idaeus*.

The climatic measurements were made between March 1967 and April 1968. They were performed partly as continuous measurements of the soil temperature and partly as day and night measurements of light, temperature, relative humidity and wind velocity during different seasons. These diurnal measurements were made on three comparable days in 1967 with clear weather: in the spring April 13—14, in the summer July 7—8 and in the late autumn November 8—9.

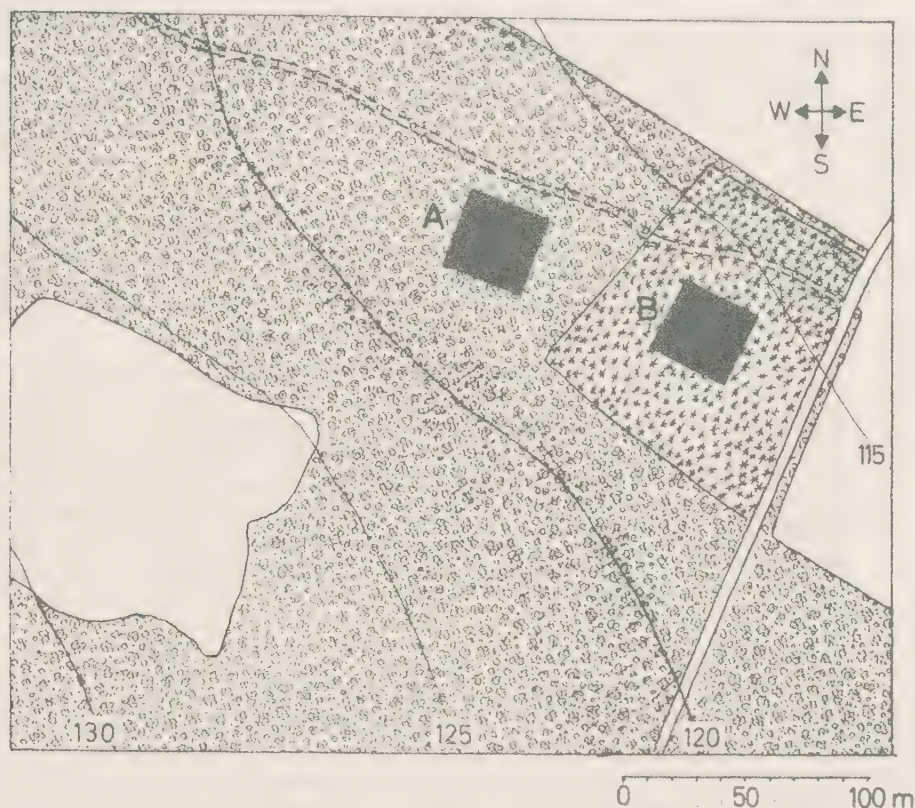


Fig. 1. Map of Kongalund, Scania, Sweden. Contourlines are indicated and height above sea level is given in metres. — A = measuring area in the beech forest. — B = measuring area in the spruce forest.

INSTRUMENTS, METHODS AND ERRORS

LIGHT was measured with an "Eel Lightmaster Photometer" which has a selenium cell and is directly read in lux (lumen/m²). The effective range covers 300—700 mμ with a maximum sensitivity at 500—600 mμ. Incoming light was measured in a horizontal plane 50 cm above the ground at a fixed point. In this way incoming light through holes in the canopy may be included. During the summer day the light in an open field, north of the forests, was also measured in order to calculate the relative light intensities. As only one photometer was used all readings could not be done at exactly the same time but within a time interval of a few minutes. However, as the sky was cloudless this did not influence the comparison. The accuracy of the instrument is difficult to estimate, as the original calibration is gradually changing. According to TURNER (1958) it may amount to $\pm 12\%$. The values would

therefore be better expressed as relative values (WALTER 1960 p. 355). However, using only relative values certain characteristic features might disappear and sometimes the values may be misleading (ANDERSSON 1964). In Fig. 2 the values measured directly in lux have been used. Due to the instability of the photometer these figures cannot be regarded as true values, but for an ecological comparison they are satisfying as they are measured with the same gauge.

In Table 1 the planimetric calculated light quantities/day (klux/day) are given, together with values in cal/cm²/day which have been approximately transformed from lux/day, using values from TURNER (1958). For cloudy weather he states 1440 lux/hour=1 cal/cm²/hour, for sunny weather 1260 lux/hour=1 cal/cm²/hour. My measurements were made mostly in tree-shade and therefore the figure for cloudy weather was used.

This calculation and transformation must be regarded as rough, as TURNER's figures are valid for an open field and not a forest where the spectral composition of light is different (cf. p. 338). Radiation figures from Svalöv, ten km SW Kongalund, are also given in Table 1 (SMHI 1967). As can be seen the values from 7—8/7 in an open field in Kongalund and Svalöv differ only slightly. However, this does not ensure that the figures in cal/cm²/day of the forests would be equally reliable. Including the instrumental error, the changes in light composition and the fact that the readings were made only once or twice an hour, it seems reasonable to estimate a total error of $\pm 15\%$ of the transformed values.

TEMPERATURE. The three day and night temperature measurements were recorded by a Honeywell Brown Electronic recorder (driving force a 12 V battery converted to 120 V), fitted with wires and thermocouples of copper-constantan. The temperature was recorded directly in °C and 24 points were read within seven minutes. The recorder was placed in the middle between the two measuring points A and B and wires 30 m long were used.

The thermocouples were placed in a vertical profile at 100 cm, 25 cm, 10 cm and 5 cm above the ground and in the soil at ± 0 cm (in the litter), —5 cm, —10 cm and —25 cm. The thermocouples in the soil were isolated with "RX-lim", a transparent cement. The thermocouples above the ground were protected from direct sunshine by a paper with black inside and bright outside surfaces (cf. PÅHLSSON 1966). The accuracy, including errors, in calibration and readings from the recorder paper, is estimated as $\pm 0.2^\circ\text{C}$.

At the continuous recording of soil temperature throughout the year, thermographs fitted with distance wires (Lambrecht K.G. Göttingen, type 257) were used. Each thermograph had two sensitive bodies 15 cm long. One thermograph was placed inside each sampling area, with one sensitive body in the surface just below the litter and one at a depth of 25 cm.

The accuracy of this apparatus was $\pm 0.3^\circ\text{C}$, providing calibration was made before and after measuring. The horizontal variation of temperature inside the whole sampling area at any one time was more than 0.3°C , at least in the surface layer. However in the calculated average values for whole days and weeks, as is the case in Figs. 4—5, this variation ought to be reduced.

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Table 1

A. Planimetric calculated values in klux/day and approximately transformed values in cal/cm²/day (1967).

Period	Forest type	klux/day	cal/cm ² /day	Ratio beech/spruce
13—14/4	Beech forest	239	166 (36%)	17.3/1
	Spruce forest	13.8	9.6 (2%)	
	In open field (Svalöv)	—	461 (100%)	
7— 8/7	Beech forest	18.2	12.7 (3%)	0.8/1
	Spruce forest	22.6	15.7 (4%)	
	In open field (Kongalund)	—	416 (104%)	
	In open field (Svalöv)	—	402 (100%)	
8— 9/11	Beech forest	40.1	27.8 (25%)	7.3/1
	Spruce forest	5.5	3.8 (3%)	
	In open field (Svalöv)	—	111 (100%)	

B. Calculated yearly energy input

Beech forest		cal/cm ² /year		
May—October	—	1890	(3%)	—
November—February	—	1760	(30%)	—
March—April	—	4510	(30%)	—
		Σ 8160		
Spruce forest	—	Σ 2520	(3%)	3.2/1
In open field (Svalöv)	—	Σ 84155	(100%)	—

The length of the sensitive body also ensured an integration of soil temperature.

WIND VELOCITY was measured with R. Fuess type anemometers, one of which was placed inside each sampling area at a height of 50 cm above the ground. This is a very sensitive instrument.

RELATIVELY HUMIDITY was measured with Lambrecht's hair hygrometers no. 194. These were placed at three levels: 0 cm (in the litter), 5 cm and 50 cm above the ground, with two meters at each level. They were protected against direct sunlight by aluminium sheets. All the hygrometers were calibrated before the measurements. The accuracy, estimated from the difference of the two meters at each level, was $\pm 3\%$. However the hygrometers never gave a 100 % deflection in total watersaturated air, but would stay at 95—98 %. Therefore a 95 % limit which can be regarded as 100 %, was drawn in the diagrams.

LIGHT — RESULTS AND CONCLUSIONS

During the three measuring days the light was read off once or twice an hour. As clear days were chosen for sampling, the sky was almost cloudless the whole time, except for July 8th, when there were some clouds. Apart from this the measured light intensities can be regarded as maximum values.

During the spring day (Fig. 2 A) high light intensities were obtained in the defoliated beech forest. In the middle of the day the light intensity could be up to forty times greater in the beech forest compared with the spruce forest. During the summer day (Fig. 2 B) the light conditions were similar in the two types of forests, or slightly higher in the spruce forest. During the late autumn day (Fig. 2 C) the light intensities were low but as the leaves had fallen the intensities were again greater in the beech forest. In the middle of the day the light intensity was ten times greater in the beech forest than in the spruce forest.

Out of the 24 hour period 14 hours were light during the spring day, 17 during the summer day and 9 during the late autumn day. In the planimetric calculation of light quantities/day (klux/day) the light proportion beech : spruce were 17 : 1 for the spring day, 0.8 : 1 for the summer day and 7.3 : 1 for the late autumn day. Expressed in energy units, cal/cm²/day, the relative proportions would be the same (cf. Table 1). However, as mentioned earlier, this transformation is not absolutely correct, mostly owing to the changes in the spectral composition of light when passing through the canopy. Concerning the spectral composition several scientists have shown obvious differences between thinleaved deciduous forests and needle forests (KNUCHEL 1914, SEYBOLD 1936, EGGLE 1939, COMBE 1957). ATKINS et al. (1937) found the same differences between a beech and an evergreen *Quercus ilex* forest. The difference is that in deciduous woods the transmission and reflection from leaves give rise to a dark red-green shade, rich in dark red and infrared rays. The blue and violet rays are absorbed to a great extent by the leaves. In spruce forests there is instead a blueshade, where the spectrum is almost the same as in full daylight, except for relatively more blue light during clear days. The ecological importance of these differences is not fully known. Taking the figures from Svalöv as 100 % and estimating the percentage of energy in the beech forest to 3 % during May—October, 30 % during November—April and in the spruce forest to 3 % during the whole year, it is possible to get an idea of the total radiation reaching the ground in the two ecosystems (Table 1 B). Incoming radiation to the ground of the beech forest is then three times greater than that of the spruce forest. It is worth

Fig. 2. Light conditions during the three measuring days. Lux are given on a logarithmic scale. Sunset and sunrise are indicated by arrows. — A: The spring day, April 13—14, 1967. — B: The summer day, July 7—8, 1967. — C: The late autumn day, November 8—9, 1967.



Table 2. Some calculated values on relative light intensities in percentage during July 7—8, 1967.

7/7—8/7	Beech forest	Spruce forest
12.00	2.9	3.1
14.00	2.9	4.0
16.00	3.4	2.7
18.00	2.1	2.8
20.00	4.6	7.0
22.00	—	—
24.00	—	—
02.00	—	—
04.00	3.1	6.2
06.00	2.8	4.5
08.00	4.0	6.0
10.00	4.3	5.8
12.00	2.6	4.1

noticing that more than half of this radiation of the beech forest comes during the spring period March—April before the leaves are bursting. However it is important to remember that the relative light intensities vary from hour to hour and from day to day, depending on diffuse or direct sunlight (ANDERSSON 1964). The yearly average values of relative light intensity given above, can be justified as the difference is great and similar fluctuations will occur in both stands.

During the summer day values of the relative light intensity, in percentage of the light in an open field have been calculated. This day may correspond to a day with high light intensities of the vegetation period June—July. At least during June there is a restricted growth of inter-alia *Stellaria nemorum* ssp. *glochidosperma*, *Lamium galeobdolon*, *Oxalis acetosella* and *Convallaria majalis* in the beech forest, while in the spruce forest a very resiricted growth of scattered individuals of inter-alia *Oxalis acetosella*, *Rubus idaeus* and *Dryopteris spinulosa* can be seen, in spite of the relatively greater light intensities in the spruce forest (Table 2).

According to LUNDEGÅRD (1921) the compensation point of several shade plants is found at a relative light intensity of approximately 1 %. For positive assimilation the plants require more light. This condition seems to be fulfilled in both the beech and the spruce forest, but growth of the field layer occurs mainly in the former, in spite of more light in the spruce forest. A contributive reason for this could be that other site conditions, e.g. the water conditions and the degree of acidity demand more light for growth in the spruce forest. The volume per-

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centage water in the upper horizons of the soil is thus almost double and the pH is half a unit higher in the beech forest compared with in the spruce forest. ELLENBERG (1939) has found that the minimum light for a particular species is higher on a more poor and acid soil than on a richer and more neutral one. This implies that "plants can manage with less light, the more favourable other growth conditions are" (WALTER 1960 p. 366, translated from German). The light spring period in the beech forest during April and the beginning of May might also be of importance to the summer plants, which are often able to start their growth at this time.

Judging from the summer day there seems to be no great difference between the beech and the planted spruce forest regarding the light conditions during the leafed period May—August. The light intensities in the spruce forest are surprisingly similar and very low on all three occasions and might be so during the whole year. In the beech forest light ought to be considerably higher during the period November—April and especially during the spring before the verdancy (cf. ANDERSSON 1964). The stronger radiation and energy input in the beech forest during this time makes the growth of spring species possible and causes an increased soil temperature (see p. 346). In the planted spruce forest the light must be considered as one of the most important limiting site factors for the ground vegetation. Probably it is the most important one, which has been stressed e.g. by SCHLÜTER (1966) and RHEINHEIMER (1959). The latter studied the immigration of plant species into planted spruce forests and found that plants will not immigrate to a great extent until there is a relative light intensity above 7 %. The spruce forest I have investigated is, in this respect, just on the limit to permit the growth of ground vegetation.

TEMPERATURE — RESULTS AND CONCLUSIONS

The daily variations during spring, summer and late autumn are given in Fig. 3 A—C. In these isopleth diagrams every second degree has been marked with isotherms (cf. PÅHLSSON 1966). During the spring day (Fig. 3 A) there was a quick warming of the air immediately above the soil surface in the beech forest, owing to the strong, direct incoming radiation. The warmth was soon transmitted to higher air layers. Maximum temperature of 12°C was reached in the afternoon. In the spruce forest the warming occurred more evenly, with a maximum temperature of about 10°C in the afternoon. Cooling at night

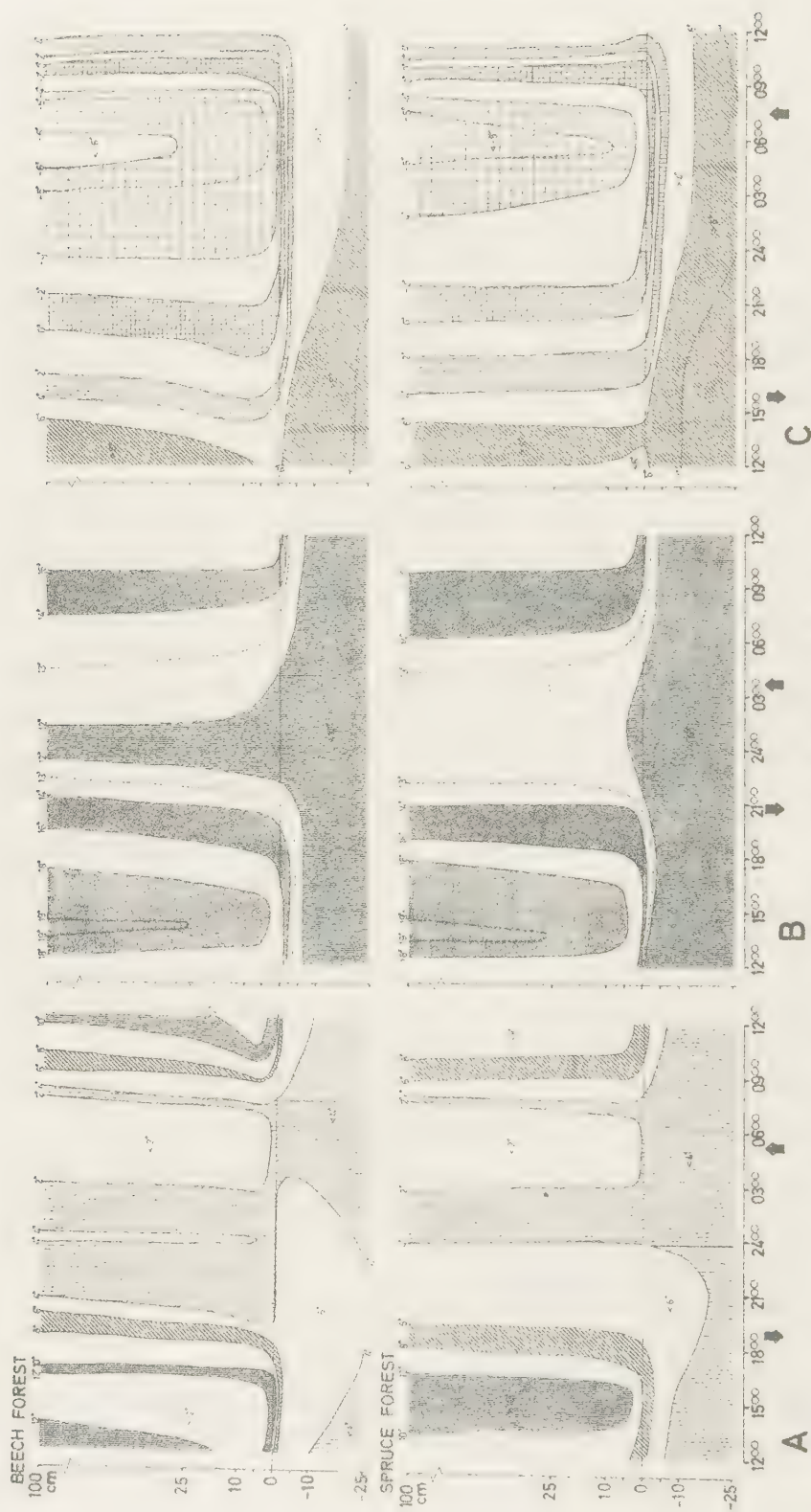


Fig. 3. Isopleth diagrams showing the daily variation of temperature in the beech and the spruce forests during the three measuring days. Sunset and sunrise are indicated by arrows. --- A: The spring day, April 13-14, 1967. --- B: The summer day, July 7-8, 1967. --- C: The late autumn day, November 8-9, 1967.

occurred faster in the beech forest, due to a greater outgoing radiation, and the minimum temperature, which differed only slightly from that of the spruce forest, was reached just before sunrise nearest to the soil. It was half a degree cooler in the beech forest (0.8°C and 1.3°C respectively). In both the beech and spruce forest there were distinct litter layers, which owing to their loose structure and low heat-conductivities, must have acted as insulators. To some extent this may have levelled off the differences in radiation.

The soil temperatures fluctuated around 4°C but in the beech forest there was a relatively strong warming of the soil and the effect of this warming could be seen long into the night. The soil of the spruce forest was not warmed to the same degree and it cooled off faster. Contributing to the longer maintained warming effect in the beech forest soil was certainly the greater water content. In the upper soil horizons of the beech forest there were 40—45 vol. % water, while in the spruce forest there were only 25—30 vol. %. The higher incoming radiation in the beech forest made a warming of a greater volume of soil and water possible. The heat conductivity increases with increased water content (GEIGER 1961, WALTER 1960). The warmth was therefore transmitted quicker to greater depth in the beech forest soil and the result was a more retained warmth, which became evident at cooling.

During the summer day (Fig. 3 B) the temperature conditions in the beech and spruce forests were almost identical. A maximum temperature of 19°C was reached about two o'clock in the afternoon. The coldest air temperature was obtained immediately after midnight with 11.9°C in the beech and 12.2°C in the spruce forest. Cooling and warming occurred slowly and very uniformly in both the forests. The soil temperatures varied between 10°C and 13°C with the warmest parts nearest to the soil surface. The soil temperature at 25 cm depth in the beech forest was about 0.6 — 0.8°C higher than in the spruce forest; however this difference cannot be read off from these schematic diagrams.

The late autumn day (Fig. 3 C) happened to be the first real frost day during the autumn of 1967. This meant that the air temperature started to fall in the early afternoon. It fell more quickly in the beech forest, starting close to the soil surface, as the outgoing radiation was high in the defoliated forest. During the night the air temperatures dropped several degrees below zero. Minimum was reached at about six o'clock in the morning, with -6°C in the beech and -5°C in the spruce forest. However, these temperatures were not found nearest to the soil but at higher levels. This may be explained by a local cold fog

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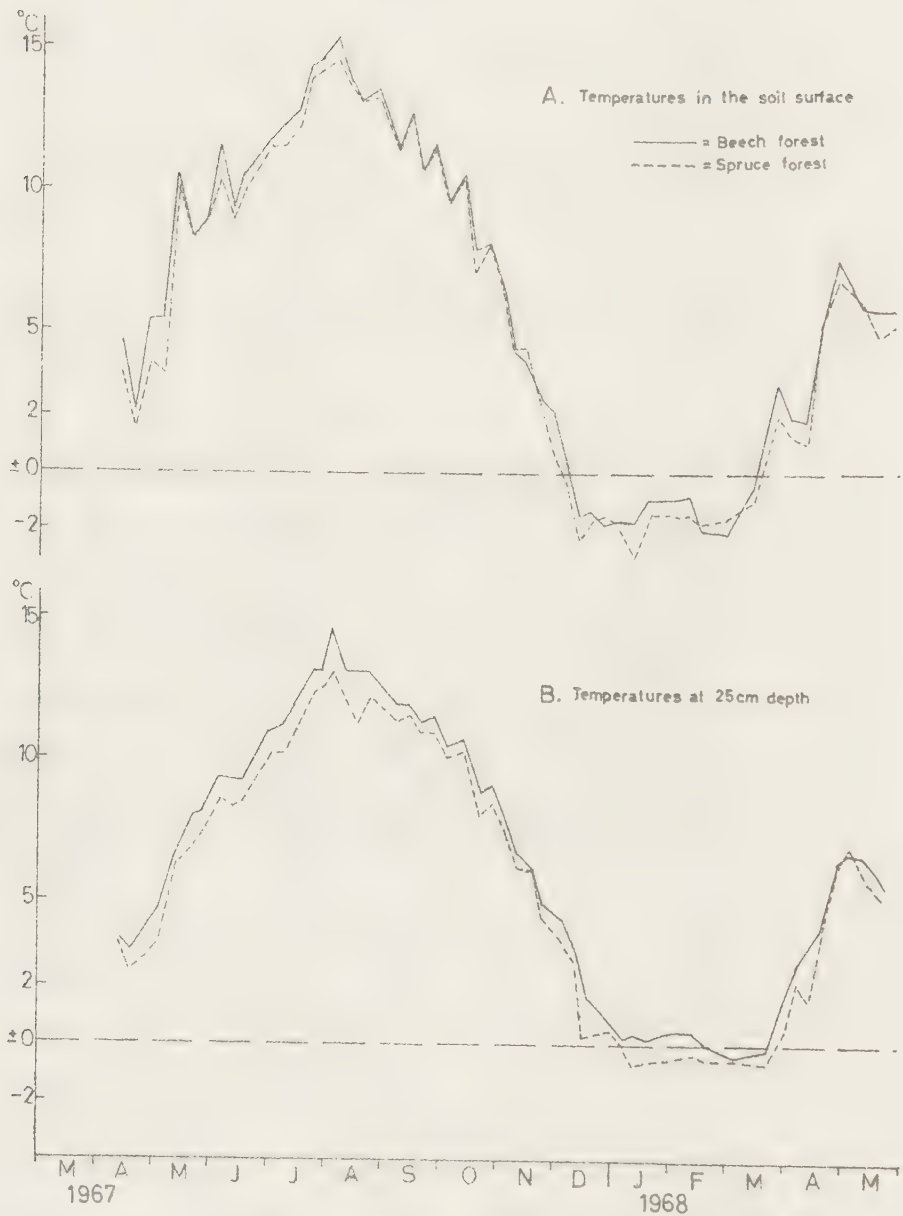


Fig. 4. The yearly variation of temperature in the soil, calculated as mean values per week. — A: The temperature in the soil surface just below the litter. — B: The soil temperature at 25 cm depth.

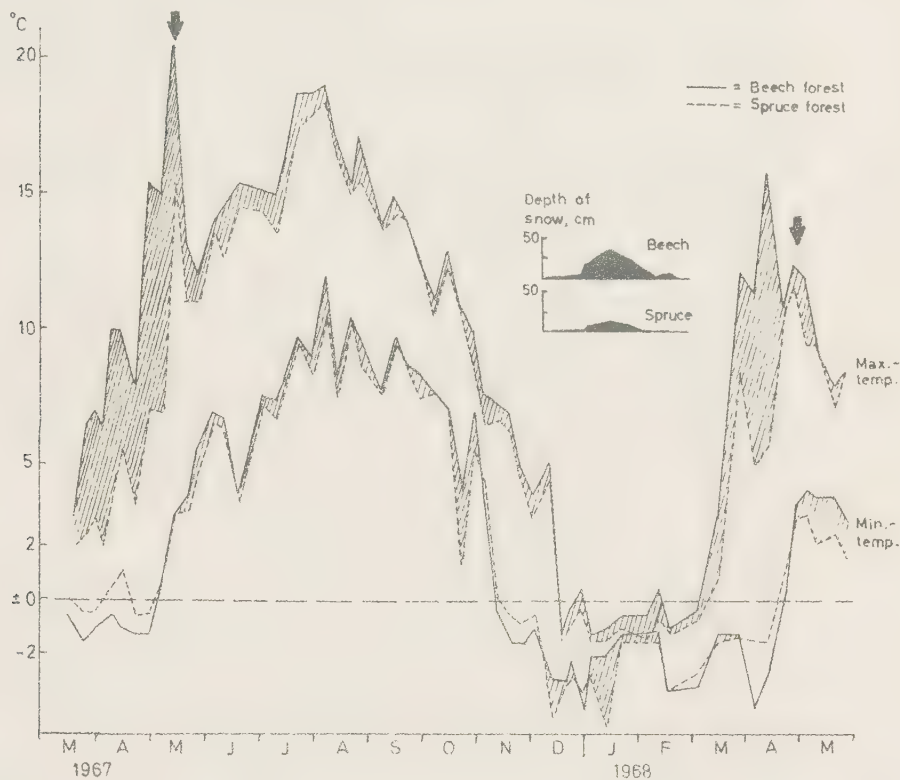


Fig. 5. The yearly variation of soil temperature. Maximum and minimum values every week from soil surface just below the litter. The beginning of verdancy in the beech forest is indicated by arrows and the higher temperature of the beech forest soil is marked with lines.

and the fact that warmth was released from the soil during the freezing period.

The soil temperatures were from the beginning 6—7°C, but during the night the upper 10—15 cm were cooled to such an extent that on the following day they were two degrees lower. The cooling was greater and occurred to a lower depth in the beech forest soil.

The yearly variation of temperature in the soil is illustrated in Figs. 4—5. In Fig 4 A and B the mean temperature/week has been calculated. This was done by reading off the temperature every second hour from the recorder paper, summing these figures for the whole week, then calculating an average week temperature. In Fig. 5 the

minimum and maximum figures obtained during each week are shown. As can be seen from Fig. 4 A and B the mean temperatures show only small deviations. However, the temperature in the beech forest soil was constantly higher, especially at 25 cm depth. In the soil surface the beech forest temperature was higher particularly during the spring periods. Also in the surface there was a marked frost during the winter, whereas at 25 cm depth freezing occurred only during short intervals and more readily in the spruce forest soil.

The course of the minimum and maximum temperatures in the soil show obvious differences (Fig. 5). During the spring before leafing there were intense temperature variations in the beech forest soil. Sometimes the maximum temperature could be several degrees higher than in the spruce forest, while the minimum temperatures could be at least one degree lower than that of the spruce forest. After bursting of the beech leaves the temperature differences were insignificant but higher maximum temperatures could be seen in the beech forest. This was also confirmed during the measuring day of July 7—8 (cf. p. 343). During the late autumn after the fall of the leaves, the minimum temperature was again lower in the beech forest until a cover of snow prevented outgoing radiation from the soil. The maximum temperature was at the same time only slightly higher in the beech forest and was in no way comparable to the corresponding temperatures in the spring. This goes back to the radiation intensities.

During winter there was a relatively thick cover of snow in the beech forest with a maximum depth of 50 cm. In the spruce forest the cover of snow did not exceed 15 cm. Probably these insolation differences contributed to the fact that the temperature of the beech forest soil was highest. After the melting of snow the intense temperature variations in the beech forest occurred again.

CONCLUSION. The daily temperature variations differ mainly during the spring and late autumn days and are obviously intimately connected to the incoming and outgoing radiation factors. During the spring day the beech forest was more intensely warmed but on the other hand it was also cooled more intensely during the night. Due to a high accumulation of heat, in the soil, the warming effects were still stronger than in the spruce forest. During late autumn the outgoing radiation was of the greatest importance, which meant that the beech forest soil was cooled more intensely in spite of the higher incoming radiation during the day compared with the spruce forest. The soil temperatures

in the two sites differed slightly throughout the year. Usually the beech forest soil was warmer, but except for the temperatures in the spring the differences were less than 1°C and therefore within the error of the method.

The temperature is of great importance to most processes in the soil. To a certain degree it is a fact that higher temperatures imply higher biologic activity and growth and quicker mineralisation and decomposition. The higher temperature in the beech forest during the spring may contribute to the fast growth of the spring species, but it must also mean a greater activity of the microflora and the microfauna, which affects the turnover of organic matter. The lower temperature in the spruce forest must be considered as one of many contributing site factors, which cause the obvious trend in formation of mor that can be seen in planted spruce forests in Scania.

RELATIVE HUMIDITY — RESULTS AND CONCLUSIONS

The results of these measurements can be seen in Fig. 6 A—C. The course of relative humidity was to some extent a mirror image of that of the temperature. Low values of relative humidity prevailed when the temperature was high and vice versa. During the spring day therefore marked differences occurred between the forests. Very low relative humidity values (< 35 %) were obtained in the beech forest just above the soil surface in the afternoon. In the evening slowly maximum values (> 95 %) were reached. During the summer day the relative humidity, just as light and temperature, was very similar in the two sites. It was high, 60—100 %, during the whole day and changes occurred very slowly. The relative humidity for the late autumn day was even higher, with variations from 80 % to 100 %. Certain differences were noticeable. During the night thus the relative humidity was highest at the 50 cm level in the beech forest, but was found just above the soil in the spruce forest. This probably depended on supercooled mist, which occurred almost to the ground in the beech forest but which was lacking close to the ground in the spruce forest. In the latter there was instead a continuous dropping of precipitated mist from the canopy which caused high relative humidity in the soil surface. Later in the night the soil surface was frozen and then the relative humidity values decreased. This happened first and to a greater extent in the beech forest but the same tendency could be seen in the spruce forest. In the morning deposited rime thawed when the temperature rose, dropped

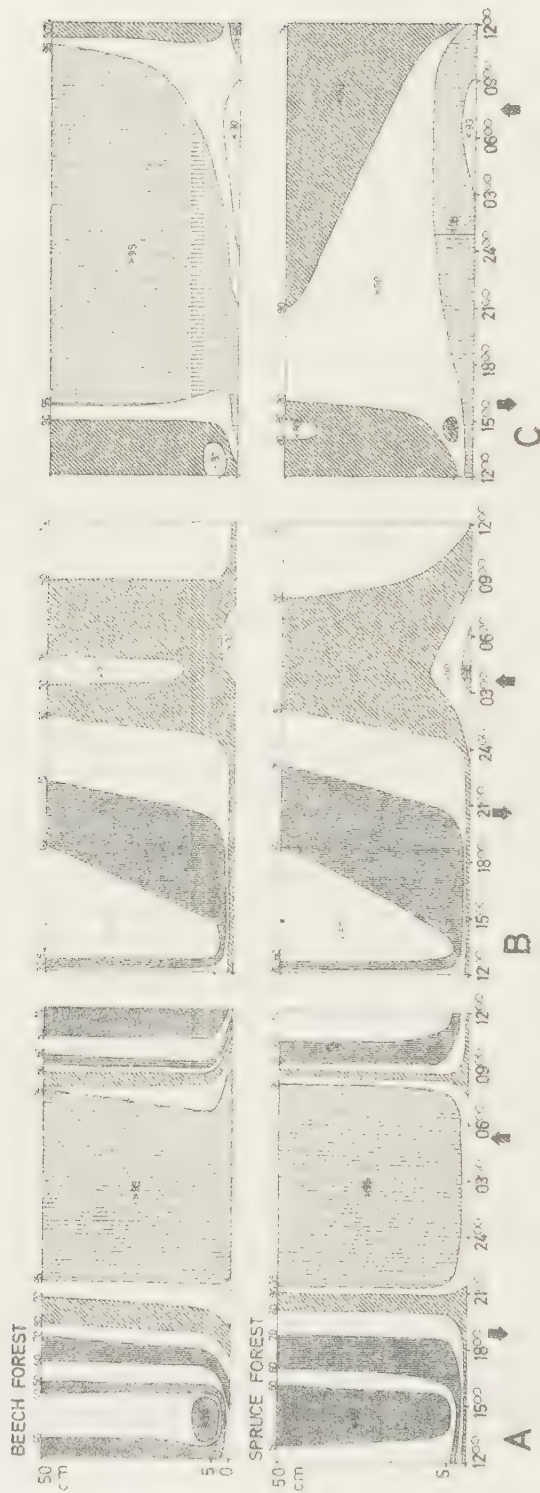


Fig. 6. The course of relative humidity during the three measuring days. Sunset and sunrise are indicated by arrows. — A: The spring day, April 13-14, 1967. — B: The summer day, July 7-8, 1967. — C: The late autumn day, November 8-9, 1967.

to the ground and caused high relative humidity values in the soil surface once again.

The humidity in the soil surface of the spruce forest was never below 80 %, though all three measuring days were chosen as days with clear weather. On the other hand in the soil surface of the beech forest the relative humidity was as low as 50 % during the spring day. Considered as an average during the whole year this implies that the soil surface in this planted spruce forest offers more humid conditions than does the beech. From the vegetation point of view this favours moist dependant shade plants, e.g. liverworts such as *Lophocolea heterophylla*, a species that is found in Kongalund and which is frequent in planted spruce forests in Scania.

Measurements of evaporation have not been performed but from the relative humidity it is possible to draw some conclusions as the evaporation ought to be inversely proportional to the relative humidity. BURGER (1934 a, b) found that the yearly evaporation in a beech forest was higher than in a spruce forest mainly because of the high evaporation in the defoliated beech forest during the spring. Certainly this also holds for Kongalund.

WIND VELOCITY

The wind velocities were very low during the three measuring days, with a maximum of 2 m/sec. The highest velocities were always obtained in the middle of the day, about noon. Due to the low wind velocities the stratification of temperature and relative humidity near the ground could be clearly illustrated (Fig. 7).

DISCUSSION

The measurements show obvious differences in the microclimate between the beech and the planted spruce forest. The climate in the beech forest was more variable with great differences between the leafed summer period and the other seasons. The climate in the spruce forest was more uniform throughout the year, which meant that the great variations valid for an open field were reduced (cf. MITSCHERLICH et al. 1965). The primary site factor causing differences between beech and spruce forests is probably incoming radiation which influences both the temperature and the relative humidity. All differences were greatest in the spring, while in the summer the conditions seemed

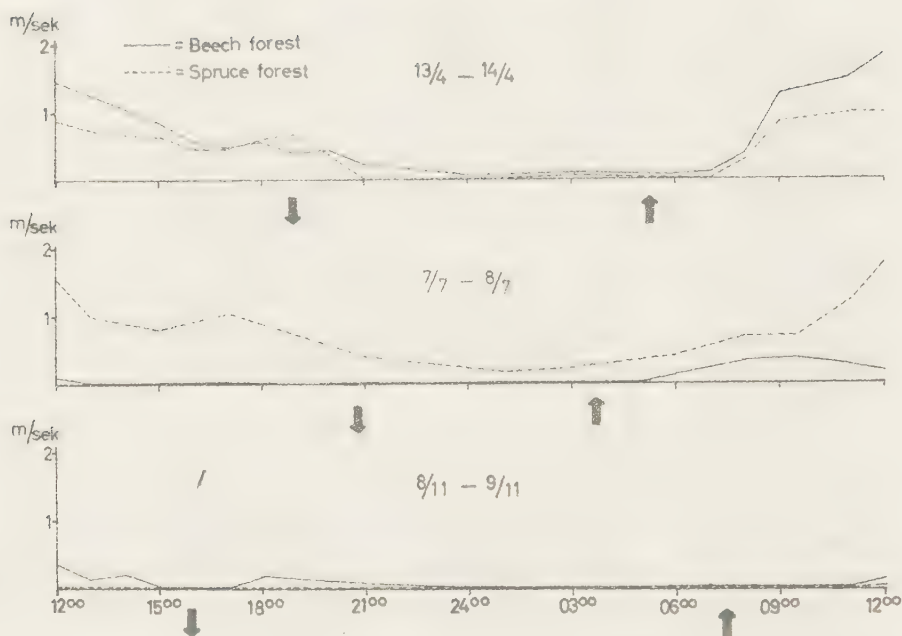


Fig. 7. The wind velocity during the three measuring days. Sunset and sunrise are indicated by arrows.

to be the same, although there were small differences in soil temperature. Also during late autumn when the beeches had dropped their leaves, the climatic differences were small owing to the low incoming radiation.

The light must be considered as the primary cause for the development of the spring flora in the beech forest and as a limiting site factor for the ground vegetation in the spruce forest. In the latter probably some other site conditions contribute to the poor development of the ground flora.

These results given are of course valid for this locality and cannot be directly applied to other forests. In addition to the general climatic features, both the cover of the canopy and the chemical and physical properties of the soil have an effect on the microclimate. Concerning planted spruce forests it might be stated that the microclimate in young, dense stands is still more unfavourable to the ground vegetation and to the microflora and microfauna of the soil, at least with regard to light and temperature conditions. In more open stands the microclimate

ought to be more favourable, which is indicated mainly by a better development of the field layer. This has also been shown in several investigations on thinning plots, e.g. by OTT (1966) and MITSCHERLICH et al. (1965).

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IV. PRECIPITATION

Precipitation, its chemical composition and effect on soil water in a beech and a spruce forest in south Sweden

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Abstract

The quantitative distribution and the chemical composition of the rainfall in a 100-years old beech forest and a neighbouring 55-years old planted spruce forest are reported. Average annual values of throughfall, stem flow and interception are estimated as 70%, 11% and 19% for the beech forest and 58%, 3% and 39% for the spruce forest of the incident rainfall in an open field. The soil of the spruce forest is about 19% drier than that of the beech forest, because of high interception and long transpiration period of the former forest.

The following chemical features are discussed: pH, conductivity, amounts of Na, K, Ca, Mg, Mn, Cl, SO₄-S, PO₄-P and tot.-N. Extrapolated annual values of nutrients in the throughfall + stem flow amount to 107 kg/ha and 215 kg/ha in the beech and the spruce forests respectively.

A high percentage of the nutrients must derive from dry deposited aerosols and this was particularly so for Na, Mg, Cl and Ca. There was no indication of the spruce forest to adhere more aerosols than the beech forest, and the higher amounts of nutrients in the rainfall of the spruce forest probably derived from stronger leaching processes of the canopy.

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1. Introduction

The present paper is part of an investigation elucidating the ecological-pedological changes occurring when spruce *Picea abies* L. is planted on ground formerly covered with beech *Fagus sylvatica* L. The aims of the actual measurements have been to compare the quantitative distribution of the rain- and soil-water, to compare qualitative features of the rainfall and to estimate annual figures of the nutrients in the rainfall, for use in calculation on ecosystem budgets (in prep.) of a beech and a spruce forest.

The quantitative measurements were performed during the period March 1967 - November 1968. Qualitative chemical analyses were made of the rain-water on four occasions in 1967 and on eight occasions in 1968.

2. Description of the site

The investigations have been performed in Kongalund, in Scania, south Sweden, a woodland described by Nihlgård (1969). A 55 years old planted spruce forest is situated side by side with a 100 years old beech forest with identical soil textural conditions. The sampling plots, A and B in Fig. 1, are 50 m apart and each 1000 m² in area.

The stand densities are about 240 and 880 trees per hectare in the beech and the spruce forests respectively. Both stands are about 25 m high and have a cover of the tree crowns of 80-90%. The average tree diameter at breast height is 39 cm in the beech forest and 28 cm in the spruce forest. The distribution on diameter classes

are: in the beech forest < 20 cm: 12%, 20-30 cm: 13%, 30-40 cm: 25%, 40-50 cm: 29%, 50-60 cm: 17% and 60-70 cm: 4%; in the spruce forest < 20 cm: 8%, 20-25 cm: 19%, 25-30 cm: 36%, 30-35 cm: 29% and 35-40 cm: 8%.

The climate (cf. Nihlgård 1969) is characterized by a yearly precipitation of 800 mm, a humidity (Tamm 1959) of 270 mm and a yearly mean temperature of 6-7°C. The prevailing wind comes from the southwest.

3. Terminology

The terminology follows White & Carlisle (1968). Thus the incident (= gross or total) rainfall is differentiated into throughfall, stem flow and interception. The latter is calculated as the difference between incident rainfall and throughfall plus stem flow.

4. Methods

4.1. Field methods

The throughfall was collected in gauges spread at random, 20 in the beech forest plot and 20 in the spruce forest plot. The gauges consisted of one litre polythene bottles in the lids of which plastic funnels (diameter 15 cm) fitted with copper nets (meshes 0.2 mm) in rings of aluminium, had been fixed by a melting process. The gauges were placed on the ground inside metal tubes (diameter 16 cm), which were dug into the ground to stabilize the gauges. The surfaces of the gauges were situated 30 cm above ground.

The stem flow was measured by two gauges in each stand, on trees with different diameters and crown projections:

	Estimated crown projections	Diameter at breast height
Beech trees . . .	28 and 57 m ²	32 and 45 cm
Spruce trees . .	3.1 and 7.1 m ²	25 and 33 cm

The gauges consisted of divided cycle-tyres stretched on a ring of porous rubber. They were placed about 1.3 m above the ground and painted with inert paraffin. The water was led into 200 l tanks of iron in the beech forest and into 25 l plastic tanks in the spruce forest. The litre values of the stem flow were transformed to mm, using the estimated crown projections of the sampling trees.

The incident rainfall was measured in a clearing (C in Fig. 1). Three gauges, of the above mentioned type, were placed around one gauge of SMHI type (SMHI Medd. 1958), diameter 16 cm fitted with a wind shelter and placed with the opening 1.5 m above the ground. The results from the SMHI gauge were usually within the range of the results from the other but on some occasions about 3% lower. In calculating the mean and the 95% confidence limits of the incident rainfall values from all four gauges were used. The SMHI gauge

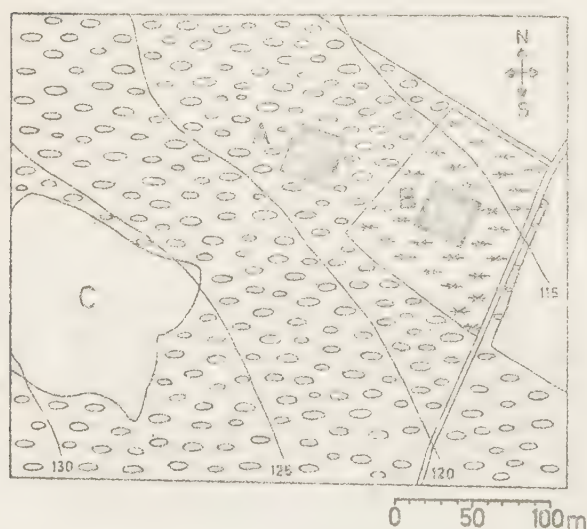


Fig. 1. Map of the experimental site in Kongalund, Scania, Sweden. 55°59'N, 13°10'E. Contour lines are indicated and height above sea level is given in m. A = measuring area in the beech forest, B = measuring area in the spruce forest, C = a clearing where the incident rainfall was measured.

was emptied each rainy day, while the other gauges were emptied every or every second week.

The yearly soil water fluctuations were followed by monthly borings down to 60 cm, using a soil auger of 22 mm inner diameter (cf. Andersson 1963). The soil water content was determined for each 10 cm (105°C). Five cores were randomly sampled from each stand. The water content is expressed on a volume basis, and the volume weights needed for these calculations were determined from cylinder samples taken from each ten cm using a steel cylinder of 385 cm³ (cf. Andersson, op cit.).

Rainwater for chemical analysis was taken during different seasons, representing defoliated periods (April, November), verdancy periods (May), summer periods (June, August) and also a defoliation period (October).

Before this rainwater was collected all the augers were replaced by clean ones, which were allowed to stand for a maximum of one week before renewed cleaning. Continuous contamination of the gauges by bird droppings and fallen leaves or needles made this re-cleaning necessary. Moreover, contamination by wind-borne dust from the ground inside the forest could be expected.

4.2. Analytical methods

In 1967 the analyses were performed on ten, and in 1968 on four composite samples from each stand of the 20 gauges measuring the throughfall. Water from both stem flow gauges was analysed. Contamination from the iron tanks used in the beech forest was small and mainly concerned iron and chloride. In the open field the rainwater of the three polythene gauges was analysed separately.

The water samples were stored at +4°C and were analysed within a month for: pH, conductivity, Na, K, Ca, Mg, Fe, Mn, Cl, SO₄, PO₄, NO₃, NH₄ and tot.-N. As pH was usually far below 6.0 the concentration of HCO₃ was negligible.

pH was determined with a pH-meter, type Beckman N-2 (accuracy ± 0.02), one day after sampling. In calculating average values of pH, the pH values were first transformed to concentration values of the hydrogen ions, and the average of these was retransformed to pH (cf. Barrett & Brodin 1955).

The conductivity (expressed in $\mu\text{mho/cm}$ with an accuracy of 1%) was determined with a conductivity meter (type Tetramatic, 4-electrode MHO-meter) one day after sampling. Using the concentrations of the ions and the ionic conductances also a calculated conductivity could be obtained. Values (20°C) of the specific ionic conductance used were: H⁺ 323, Na⁺ 45, K⁺ 6, Ca²⁺ 108, Mg²⁺ 96, Mn²⁺ 82, NH₄⁺ 66, NO₃⁻ 65, SO₄²⁻ 145, Cl⁻ 69 (cf. Landolt-Börnstein 1923, Malmer 1963).

Remaining analyses were performed directly on filtered water. The cations Na, K, Ca, Mg, Fe and Mn were determined on a Perkin-Elmer Atomic Absorption Spectrophotometer, with analytical errors normally of

1%, estimated from the standard curves. However, at very low concentrations the inaccuracy could amount to 5% or more.

Chloride was determined with a mercurimetric method using diphenylcarbazon as an indicator (Clarke 1950). Accuracy $\pm 5\%$, calculated as standard deviation of duplicated analyses (2n = 40). Sulphate was determined with a turbidimetric method using BaCl₂ and an acid seed solution (Chesnin & Yien 1950, Rossum & Villarez 1961). Accuracy $\pm 7\%$, calculated as for chloride. Brown coloured samples were treated with activated charcoal. Phosphate was determined with a colorimetric method after reduction with ascorbic acid and addition of K-antimonytartrate plus ammonium molybdate (Murphy and Riley 1962). Accuracy $\pm 7\%$, calculated as above. The serious disappearance of phosphorous in polythene gauges, stressed by several workers, was observable only in new bottles. Nitrate was tentatively determined, using a colorimetric method (accuracy $\pm 10\%$ calculated as above, with alpha-naphthylamine and sulphanilic acid after addition of HAc, BaSO₄ and MnSO₄ (cf. Bray 1945, Method 1, Procedure 1). Ammonia was tentatively determined using Nessler's reagent after addition of sodium potassium tartrate. Accuracy $\pm 7\%$, calculated as above. The tentative figures of NO₃-N and NH₄-N are not given in the tables but they were used in the calculations of anions and cations, and in the calculation of the conductivity. NO₃ and NH₄ appeared in equal quantities and usually made up the whole nitrogen content. Total nitrogen was analysed according to a macro-Kjeldahl distillation method described by Karlgren (1962). The accuracy was $\pm 6\%$, calculated as for chloride (2n = 60).

In the tables 95% confidence limits are given as calculated on the total material. The range width has been used for estimation of the standard deviation (Brown and Sallee 1964 p. 105).

4.3. Distribution of the rainfall above ground

The main results are compiled in Tab. 1. The calculated values from the winter period (see the text of Tab. 1) are founded on the experience that the stem flow and the throughfall are slightly higher in the defoliated beech forest (cf. Burger 1934), but almost the same in the spruce forest (cf. Stålfelt 1944, Rutter 1963). The mm values of the stem flow are founded on the estimated crown projections of the trees used. As the crown projection of a beech tree is large, this means that there was a great deal of water concentrated in the trunk area. This was not so in the case of a spruce tree where the stem flow quantities were small, usually only one to ten percent of that of a beech tree. This difference must be assigned to the different morphology of a beech and a spruce tree: the branches of a beech tree are directed obliquely upwards and the bark is smooth, while the branches of a spruce tree are right-angled or slightly directed downwards and the bark is rough.

Tab. 1. Distribution of the rainfall in the beech and the spruce forests during 1967-68. Figures expressed in mm and as a percentage of the incident rainfall. Figures in parentheses = 95% confidence limits.

Period	Incident rainfall (n = 4)	Beech forest		Σ		Spruce forest		Σ		Calculated interception	
		Throughfall (n = 20)	Stem flow (n = 2)			Throughfall (n = 20)	Stem flow (n = 2)			Beech f.	Spruce f.
March 26 - Dec. 4 1967 ¹⁾ ...mm	693 (±7)	490 (±29)	78 (±20)	568 (±49)		402 (±28)	16 (±4)	418 (±32)		125	275
%	100.0 (1.0)	70.8 (±4.2)	11.3 (±2.9)	82.1 (±7.1)		57.9 (±4.1)	2.3 (±0.6)	60.2 (±4.7)		17.9	39.8
Dec. 5 - Febr. 5 1967-68 ²⁾ ...mm	250	182	30	212		145	10	156		38	95
%	100.0	73.0	12.0	85.0		58.0	4.0	62.0		15.0	38.0
Febr. 6 - Nov. 12 1968 ³⁾ ...mm	638 (±6)	422 (±25)	76 (±20)	498 (±45)		360 (±2.5)	26 (±7)	386 (±32)		140	252
%	100.0 (±1.0)	66.2 (±3.9)	11.9 (±3.2)	78.1 (±7.1)		56.5 (±3.9)	4.1 (±1.1)	60.6 (±5.0)		21.9	39.4
12 months.....mm	1013	718	116	834		582	27	609		179	404
%	100.0	70.9	11.4	82.3		57.5	2.6	60.1		17.7	39.9
April-67- March-68.....mm	885	608	102	710		515	37	552		175	333
%	100.0	68.7	11.5	80.2		58.2	4.2	62.4		19.8	37.6

¹⁾ = values founded on 30 emptyings of all the raingauges. ²⁾ = winter period with snow or frozen rainwater in the gauges. The values for the forests are estimated from 14 emptyings of the SMHI rain gauge measuring the incident rainfall. ³⁾ = values founded on 21 emptyings of all the raingauges.

Expressed in mm both the throughfall and the stem flow values differ distinctly between the two stands. The throughfall, as a percentage of the incident rainfall, is 10-12% higher and the stem flow about 8% higher in the beech forest (Tab. 1). Thus the interception is about twice as high in the spruce forest and amounts to 40% of the incident rainfall. This implies 160-220 mm less water supplied to the ground every year compared with the beech forest.

The results obtained are in agreement with those of Hoppe (1896) and Eidmann (in Geiger 1961: 351). The latter, however, found a lower interception in the spruce forest. Burger (1934) reports an interception of 48%, and Stålfelt (1944) 52-57% from forty years old spruce forests. Burger's results on the throughfall in a beech forest agree with mine. Reynold and Henderson (1967: 179) found a stem flow of beech trees that was lower than mine expressed in litres/mm.

6. Precipitation and soil water

The beech forest soil received more precipitation water and was constantly wetter than the soil of the spruce

forest (Fig. 2). The yearly variation was less in the beech forest soil. There was no indication of an interference of the ground water as the decrease in soil moisture occurred downwards and the lowest volume percents were always found in the deeper horizons.

Assuming that the ground water level does not interfere the following water relation is valid during each period between two sampling occasions: $S_1 = S_0 + P - L$ or $P = \pm \Delta S + L$, where P is the precipitation, ΔS is the change ($S_1 - S_0$) in the total soil water content and L is losses in the form of evaporation, transpiration, run off or drainage water. In Tab. 2 these values are given for the whole period, and the course of S and P values are illustrated in Fig. 3.

Provided that S was the same at the end as at the beginning of the period, $\Sigma \Delta S$ should equal zero and ΣL should equal ΣP . However, evapotranspiration had already started in May 1968, obviously earlier in the spruce forest (cf. Fig. 3) and ΔS was slightly lower in this forest compared with the beech forest, -25 and -3 mm respectively.

The spruce forest soil was, on average, 19% or 42 mm (range 25-63 mm) drier than the beech forest soil, with

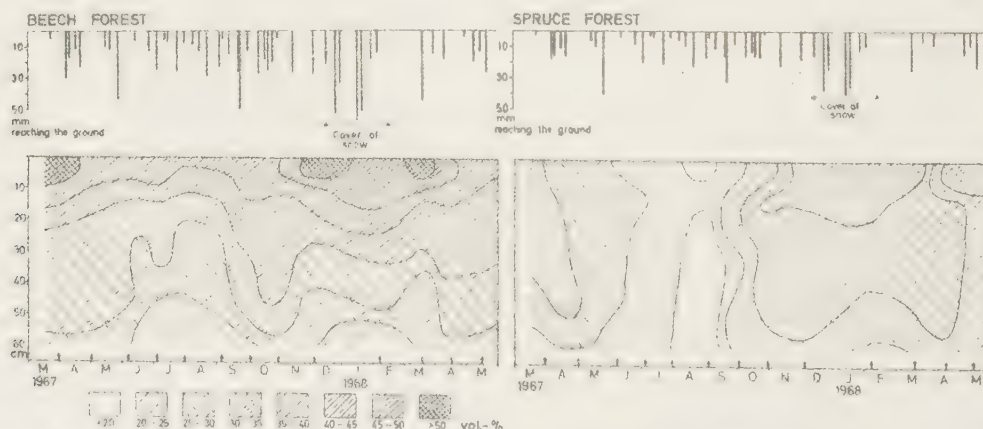


Fig. 2. Isopleth diagram showing the variations of the soil water content down to 60 cm depth in percentage volume of the beech and the spruce forest soils during March 1967-May 1968. The sampling occasions are indicated by arrows. The precipitation (= throughfall + stem flow) is given above.

beech forest and the incident rainfall for different elements increases in the order $N < P < S < Na < Ca < Cl < Mg < K < Mn$. The corresponding ratio between the rainfall of the spruce forest and the incident rainfall increases in the order $N < Na < Cl < Ca < Mg < S < P < K < Mn$. This means that the relative increase in potassium and manganese is prominent in both forests,

but sulphur and phosphorous have increased relatively more in the spruce forest.

Nitrogen shows the lowest increase in the rainfall of both forest types and in the beech forest its increase is almost negligible. Cf. Carlisle et al. (1966) who in fact found a decrease in the nitrogen content in the rainwater that passed the canopy of a mixed deciduous

Tab. 3 A-B. Average values in kg/ha of the analysed nutrients of the rainwater from twelve occasions during 1967-68. "Difference" denotes the difference between throughfall + stem flow and incident rainfall, and thus indicates the increase or decrease of nutrients compared with the incident rainfall. Figures in parentheses = 95 % confidence limits. - 3 A. The beech forest. - 3 B. The spruce forest.

Table 3A

Date	Precipitation type	Precip. quant. mm	Na kg/ha	K kg/ha	Ca kg/ha	Mg kg/ha	Mn kg/ha	Cl kg/ha	SO ₄ -S kg/ha	PO ₄ -P g/ha	Tot.-N kg/ha	pH
April 8 1967	Inc. rainfall	22.1	0.04	0.01	0.05	0.005	<0.001	0.09	0.14	1.37	0.18	5.2
	Throughfall	14.2	0.07	0.06	0.03	0.014	<0.001	0.10	0.14	0.88	0.11	5.7
	Stem flow	2.6	0.02	0.01	0.01	0.001	<0.001	0.01	0.05	0.16	<0.01	4.5
	Difference	-3.3	+0.05	+0.06	-0.01	+0.010	±0.00	+0.02	+0.05	-0.33	-0.07	-
April 20 1967	Inc. rainfall	25.0	0.62	0.09	0.09	0.073	<0.001	0.99	0.38	1.55	0.33	5.3
	Throughfall	19.1	1.25	0.19	0.16	0.148	0.021	2.35	0.43	2.95	0.23	5.1
	Stem flow	3.6	0.38	0.10	0.10	0.037	0.008	0.73	0.14	0.34	<0.01	3.9
	Difference	-2.3	+1.01	+0.20	+0.17	+0.112	+0.029	+2.09	+0.19	+1.74	-0.10	-
July 3 1967	Inc. rainfall	29.6	0.09	0.15	0.04	0.012	<0.001	0.12	0.17	3.09	0.17	5.3
	Throughfall	19.0	0.12	0.35	0.14	0.056	0.063	0.20	0.35	8.84	0.15	6.1
	Stem flow	5.5	0.05	0.21	0.02	0.011	0.003	0.07	0.22	0.87	<0.01	4.6
	Difference	-5.1	+0.08	+0.41	+0.12	+0.055	+0.066	+0.15	+0.40	+6.62	-0.02	-
Nov. 11 1967	Inc. rainfall	30.3	0.59	0.22	0.24	0.074	<0.001	1.14	0.35	1.88	0.51	5.5
	Throughfall	21.0	2.09	0.86	0.73	0.327	0.139	4.23	0.99	1.96	0.43	5.5
	Stem flow	5.9	0.23	0.47	0.09	0.050	0.023	0.25	0.30	0.18	<0.01	5.6
	Difference	-3.4	+1.73	+1.1	+0.58	+0.303	+0.162	+3.34	+0.94	+0.26	-0.07	-
April 8 1968	Inc. rainfall	22.8	0.33	0.03	0.23	0.052	<0.001	0.56	0.34	0.85	0.18	5.6
	Throughfall	17.1	0.63	0.14	0.35	0.118	0.038	1.40	0.58	1.11	0.27	4.9
	Stem flow	1.0	0.05	0.05	0.03	0.009	0.005	0.09	0.07	0.14	<0.01	5.0
	Difference	-4.7	+0.35	+0.16	+0.15	+0.075	+0.043	+0.93	+0.31	+0.40	+0.09	-
May 6 1968	Inc. rainfall	22.1	0.03	0.01	0.09	0.016	<0.001	0.14	0.16	1.09	0.18	4.8
	Throughfall	15.4	0.16	0.23	0.20	0.067	0.038	0.38	0.42	3.25	0.30	5.6
	Stem flow	3.8	0.02	0.13	0.13	0.044	0.031	0.29	0.30	0.72	0.05	5.2
	Difference	-2.9	+0.15	+0.36	+0.24	+0.095	+0.069	+0.53	+0.56	+2.88	+0.17	-
May 20 1968	Inc. rainfall	34.2	0.13	0.01	0.05	0.025	0.006	0.17	0.15	1.38	0.10	5.1
	Throughfall	22.1	0.17	0.25	0.17	0.074	0.057	0.36	0.34	2.95	0.14	5.9
	Stem flow	3.8	0.03	0.08	0.02	0.006	0.004	0.08	0.10	0.13	<0.01	4.7
	Difference	-8.3	+0.07	+0.32	+0.14	+0.055	+0.055	+0.27	+0.29	+1.70	+0.04	-
June 19 1968	Inc. rainfall	29.0	0.01	0.01	0.17	0.014	0.003	0.21	0.24	2.33	0.31	5.1
	Throughfall	20.9	0.06	0.14	0.28	0.057	0.057	0.49	0.44	3.04	0.39	5.4
	Stem flow	4.2	0.02	0.02	0.02	0.007	0.005	0.09	0.13	0.37	0.05	4.8
	Difference	-3.9	+0.07	+0.15	+0.13	+0.05	+0.059	+0.37	+0.33	+1.08	+0.13	-
June 28 1968	Inc. rainfall	55.9	0.17	0.07	0.13	0.027	0.009	0.36	0.74	4.33	0.69	5.0
	Throughfall	34.5	0.22	0.43	0.42	0.105	0.110	0.59	0.87	10.81	0.65	5.7
	Stem flow	7.1	0.05	0.03	0.03	0.008	0.008	0.13	0.20	0.79	0.01	5.0
	Difference	-14.3	+0.10	+0.39	+0.32	+0.086	+0.109	+0.36	+0.33	+7.27	-0.03	-
Aug. 19 1968	Inc. rainfall	28.9	0.17	0.08	0.08	0.042	0.003	0.47	0.15	3.50	0.26	5.7
	Throughfall	17.3	0.27	0.30	0.31	0.069	0.076	0.99	0.32	1.49	0.21	5.7
	Stem flow	2.2	0.03	0.09	0.01	0.003	0.002	0.12	0.06	0.23	0.03	5.3
	Difference	-9.4	+0.13	+0.31	+0.24	+0.030	+0.075	+0.64	+0.23	-1.78	-0.02	-
Oct. 11 1968	Inc. rainfall	58.1	0.07	0.08	0.13	0.017	0.019	0.16	0.25	3.78	0.32	5.1
	Throughfall	42.4	0.14	0.73	0.44	0.082	0.112	0.68	0.74	4.46	0.33	5.9
	Stem flow	8.0	0.02	0.30	0.01	0.002	0.004	0.19	0.12	0.83	0.01	5.3
	Difference	-7.7	+0.09	+0.95	+0.32	+0.067	+0.097	+0.71	+0.61	+1.51	+0.02	-
Nov. 12 1968	Inc. rainfall	24.6	0.02	0.01	0.11	0.008	<0.001	0.05	0.12	1.53	0.09	5.8
	Throughfall	11.0	0.06	0.11	0.21	0.027	0.027	0.15	0.10	0.82	0.07	6.2
	Stem flow	6.0	0.10	0.07	0.05	0.016	0.015	0.07	0.07	0.86	0.02	5.1
	Difference	-7.6	+0.14	+0.17	+0.15	+0.035	+0.042	+0.17	+0.05	+0.15	±0.00	-
Σ 1967-1968	Inc. rainfall	383	2.27	0.76	1.41	0.37	0.04	4.5	3.19	26.7	3.32	5.2
	Throughfall	254	(±0.20)	(±0.14)	(±0.13)	(±0.02)	(±0.02)	(±0.4)	(±0.45)	(±3.2)	(±0.33)	(±0.1)
	Stem flow	54	5.24	3.79	3.44	1.14	0.74	11.9	5.72	42.6	3.28	5.7
	Difference	(±16)	(±1.05)	(±0.65)	(±0.28)	(±0.15)	(±0.12)	(±1.8)	(±0.86)	(±9.4)	(±0.26)	(±0.1)
Extra-polated annual values	Inc. rainfall	950	5.6	1.9	3.5	0.91	0.10	11.1	7.9	66	8.2	5.2
	Throughfall	663	13.7	9.9	9.0	3.00	1.93	31.2	14.9	111	8.5	5.7
	Stem flow	109	2.0	3.2	1.1	0.39	0.22	4.3	3.6	11	0.4	4.8
	Difference	-178	+10.1	+11.2	+6.6	+2.48	+2.05	+24.4	+10.6	+56	+0.7	-

Table 3B

Date	Precipitation type	Precip. quant. mm	Na kg/ha	K kg/ha	Ca kg/ha	Mg kg/ha	Mn kg/ha	Cl kg/ha	SO ₄ -S kg/ha	PO ₄ -P g/ha	Tot.-N kg/ha	pH
April 8 1967	Inc. rainfall	22.1	0.04	0.01	0.05	0.005	<0.001	0.09	0.21	1.37	0.18	5.2
	Throughfall	14.0	0.61	0.28	0.09	0.082	0.077	0.84	1.10	21.70	0.25	4.7
	Stem flow	1.7	0.24	0.17	0.08	0.045	0.026	0.34	0.66	5.98	0.05	3.0
	Difference	-6.7	+0.81	+0.44	+0.12	+0.122	+0.103	+1.09	+1.55	+26.31	+0.12	-
April 20 1967	Inc. rainfall	25.0	0.62	0.09	0.09	0.073	<0.001	0.99	0.38	1.55	0.33	5.3
	Throughfall	15.8	1.34	0.50	0.18	0.173	0.104	2.31	1.14	6.37	0.38	4.6
	Stem flow	0.4	0.11	0.95	0.03	0.018	0.010	0.21	0.20	1.86	0.02	2.9
	Difference	-8.8	+0.83	+0.46	+0.12	+0.118	+0.114	+1.53	+0.96	+6.68	+0.07	-
July 3 1967	Inc. rainfall	29.6	0.09	0.15	0.04	0.012	<0.001	0.12	0.17	3.09	0.17	5.3
	Throughfall	19.5	0.48	0.70	0.13	0.085	0.064	1.07	0.83	11.50	0.42	5.0
	Stem flow	0.6	0.07	0.10	0.03	0.011	0.006	0.17	0.16	4.93	0.04	3.2
	Difference	-9.5	+0.46	+0.65	+0.12	+0.084	+0.070	+1.12	+0.82	+13.34	+0.29	-
Nov. 11 1967	Inc. rainfall	30.3	0.59	0.22	0.24	0.074	<0.001	1.14	0.35	1.88	0.51	5.5
	Throughfall	20.9	2.57	1.86	1.68	0.599	0.401	4.74	4.13	41.42	1.89	4.2
	Stem flow	0.9	0.43	0.39	0.24	0.090	0.047	0.75	1.29	2.90	0.16	2.7
	Difference	-8.5	+2.41	+2.03	+1.68	+0.615	+0.448	+4.35	+5.07	+42.44	+1.54	-
April 8 1968	Inc. rainfall	22.8	0.33	0.03	0.23	0.052	<0.001	0.56	0.34	0.85	0.18	5.6
	Throughfall	8.6	0.50	0.34	0.36	0.118	0.099	0.84	0.79	1.38	0.22	5.1
	Stem flow	0.1	0.01	0.01	0.02	0.004	0.002	0.10	0.11	0.30	0.03	3.9
	Difference	-14.1	+0.18	+0.32	+0.15	+0.070	+0.101	+0.38	+0.56	+0.83	+0.07	-
May 6 1968	Inc. rainfall	22.1	0.03	<0.01	0.09	0.016	<0.001	0.14	0.16	1.09	0.18	4.8
	Throughfall	14.4	0.68	0.83	0.71	0.259	0.189	1.45	1.51	7.35	0.59	4.8
	Stem flow	0.6	0.06	0.08	0.07	0.020	0.011	0.13	0.22	1.40	0.04	3.0
	Difference	-7.1	+0.71	+0.91	+0.69	+0.263	+0.200	+1.44	+1.57	+7.66	+0.43	-
May 20 1968	Inc. rainfall	34.2	0.13	0.01	0.05	0.025	0.006	0.17	0.15	1.38	0.10	5.1
	Throughfall	2.16	0.59	0.66	0.43	0.178	0.154	1.37	1.25	10.51	0.82	4.5
	Stem flow	1.6	0.36	0.32	0.33	0.102	0.058	0.72	1.02	3.49	0.24	2.8
	Difference	-11.0	+0.82	+0.98	+0.71	+0.255	+0.206	+1.92	+2.12	+12.62	+0.96	-
June 19 1968	Inc. rainfall	29.0	0.01	0.01	0.17	0.014	0.003	0.21	0.24	2.33	0.31	5.1
	Throughfall	22.3	0.40	0.60	0.53	0.115	0.101	1.00	1.41	30.02	1.60	4.5
	Stem flow	1.3	0.12	0.16	0.06	0.016	0.010	0.28	0.45	7.56	0.34	3.2
	Difference	5.4	+0.51	+0.75	+0.42	+0.117	+0.108	+1.07	+1.62	+35.25	+1.63	-
June 28 1968	Inc. rainfall	55.9	0.17	0.07	0.13	0.027	0.009	0.36	0.74	4.33	0.69	5.0
	Throughfall	34.7	0.53	0.82	0.41	0.132	0.128	1.53	1.58	22.13	1.21	4.5
	Stem flow	1.6	0.20	0.24	0.12	0.039	0.024	0.44	0.64	5.83	0.23	3.1
	Difference	-19.6	+0.56	+0.99	+0.40	+0.144	+0.143	+1.66	+1.48	+23.63	+0.75	-
Aug. 19 1968	Inc. rainfall	28.9	0.17	0.08	0.08	0.042	0.003	0.47	0.15	3.50	0.26	5.7
	Throughfall	13.4	0.48	0.58	0.25	0.080	0.059	1.41	0.45	1.83	0.45	5.0
	Stem flow	0.2	0.02	0.03	0.02	0.005	0.002	0.07	0.04	0.03	0.01	3.3
	Difference	-15.3	+0.33	+0.53	+0.19	+0.043	+0.958	+1.01	+0.34	-1.64	+0.20	-
Oct. 11 1968	Inc. rainfall	58.1	0.07	0.08	0.13	0.017	0.019	0.16	0.25	3.78	0.32	5.1
	Throughfall	43.2	0.76	1.35	0.51	0.166	0.081	1.47	1.89	22.21	0.82	4.4
	Stem flow	6.0	0.07	0.55	0.20	0.062	0.035	0.82	0.85	0.76	0.10	3.4
	Difference	-8.9	+0.76	+1.82	+0.58	+0.211	+0.097	+2.13	+2.49	+19.19	+0.60	-
Nov. 12 1968	Inc. rainfall	24.6	0.02	0.01	0.11	0.008	<0.001	0.05	0.12	1.53	0.09	5.8
	Throughfall	9.8	0.90	1.31	1.10	0.289	0.291	2.08	2.15	10.42	0.70	4.6
	Stem flow	0.8	0.10	0.14	0.13	0.035	0.026	0.20	0.40	0.11	0.03	3.1
	Difference	-14.1	+0.98	+1.44	+1.12	+0.316	+0.317	+2.23	+2.43	+9.00	+0.64	-
Σ 1967-1968	Inc. rainfall	383 (±4)	2.3 (±0.2)	0.8 (±0.1)	1.41 (±0.13)	0.37 (±0.02)	0.04 (±0.02)	4.5 (±0.4)	3.2 (±0.5)	27 (±3)	3.3 (±0.3)	5.2 (±0.1)
	Throughfall	238 (±16)	9.8 (±1.6)	9.8 (±1.1)	6.38 (±0.70)	2.28 (±0.30)	1.75 (±0.16)	20.1 (±2.6)	18.2 (±2.2)	187 (±28)	9.4 (±1.2)	4.5 (±0.1)
	Stem flow	16 (±3)	1.8 (±0.3)	2.3 (±0.4)	1.33 (±0.20)	0.35 (±0.07)	0.26 (±0.04)	4.2 (±0.4)	6.0 (±0.7)	35 (±8)	1.3 (±0.2)	3.1 (±0.1)
	Difference	-129	+9.3	+11.3	+6.30	+2.36	+1.97	+19.8	+21.0	+195	+7.4	-
Extra-polated annual values 1967-68	Inc. rainfall	950	5.6	1.9	3.5	0.91	0.10	11.1	7.9	66	8.2	5.2
	Throughfall	548	22.6	22.6	14.7	5.25	4.03	46.3	42.0	430	21.5	4.5
	Stem flow	32	3.6	4.5	2.7	0.90	0.52	8.6	12.2	71	2.6	3.1
	Difference	-370	+20.6	+25.2	+13.9	+5.24	+4.45	+43.8	+46.3	+435	+15.9	-

woodland. The mentioned authors also noticed that the inorganic nitrogen in the incident rainfall had been exchanged for organic nitrogen in the throughfall, thus indicating an active uptake of the inorganic ions by the leaves. This exchange was not obvious in my results of the throughfall in the beech forest.

In spite of 20 per cent less rainwater the amount of nutrients reaching the ground in the spruce forest is two or three times greater than that in the beech forest. The ratio spruce/beech of the nutrient quantities gives the following figures in increasing order: Cl 1.6, Na 1.7,

Ca 1.7, Mg 1.8, K 2.1, Mn 2.1, N 2.7, S 2.8 and P 3.3. The reason why nitrogen, sulphur and phosphorous increase relatively more in the spruce forest could be the presence and the leaching of old, dying and dead needles still remaining on the branches.

Another difference between the two stands is the high content of nutrient in the stem flow of the spruce forest. In spite of very small water quantities, expressed in mm only one third to one quarter of that in the beech forest, the amounts of nutrients of the spruce forest stem flow are two to three times higher. The ratio stem flow/

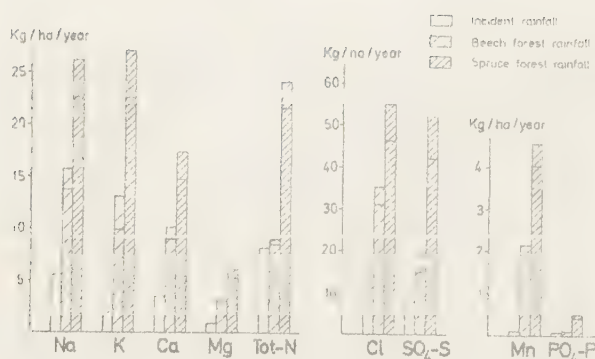


Fig. 5. Bar graphs on the extrapolated annual amounts of nutrients of the incident rainfall and of the throughfall (= the larger parts of the bars) and the stem flow (= the smaller upper parts of the bars) of the beech and the spruce forests.

throughfall of different elements is also slightly higher in the spruce forest, except for potassium.

Also the pH-values differ between the stands. The average pH of the incident rainfall is 5.2 (range 4.8–5.8). Except for the stem flow the pH-values of the beech forest throughfall are usually higher, 5.7 (range 4.9–6.2). This can be explained as an addition of basic elements and during the growing season perhaps as an uptake of CO₂ from the rainwater when passing the canopy. This uptake should shift the equilibrium reaction $\text{HCO}_3^- + \text{H}^+ \rightleftharpoons \text{H}_2\text{O} + \text{CO}_2$ to the right and lower the hydrogen ion concentration. According to Barret & Brodin (1955) a pH of 5.7 is to be expected in rainwater in equilibrium with CO₂ in the air.

In the spruce forest the pH values are very low, 4.5 as an average in the throughfall (range 4.2–5.1) and 3.1 (range 2.7–3.4) in the stem flow. Evidently acidifying substances have been added, probably by leaching of the needles, which are rich in acid organic compounds and have a low base status (Hesselman 1926, Mattson and Karlsson 1944: Tab. 7). An acid stem flow rich in nutrients is reported also by Mina (1967) on spruce trees.

The estimation of annual values of nutrients reaching the ground (Tab. 3 A–B, Fig. 5) assumes that the analysed rainwater is representative of a year and proportional to the yearly precipitation. The figures are naturally rough, as the variations between the different sampling occasions are great. The total weight of the nutrients amounts to 107 kg/ha/year in the beech forest and 215 kg/ha/year in the spruce forest. Of these 39.3 kg/ha/year can be explained by the incident rainfall while the rest must derive from leaching of the canopy or from aerosols, the latter, once being adhered or caught by the leaves and needles, are then washed down by the rainfall.

Expressed in kg/ha/mm the amounts of potassium, calcium and magnesium in the rainwater of the woodland investigated by Carlisle et al. (op. cit.) were very similar

to those of the rainwater of the beech forest. On the other hand the amounts of sodium and phosphorous are much higher and the total nitrogen content much lower in that woodland compared with the present beech forest.

The incident rainfall in the English investigation was richer in sodium and magnesium, showing the important influence of the sea in England. It was also richer in phosphorous, which perhaps was accidental. The calculated yearly supply of chloride and sulphur in the incident rainfall in Kongalund, is lower than those indicated by maps of Eriksson (1960: 81, 86).

3. Leached nutrients or aerosols?

The higher content of nutrients in the throughfall compared with the incident rainfall could be due to leaching of leaves and needles but it might also be caused by a high adsorption of aerosols, which are washed down by rainfall. To get an idea of which elements dominate in wind-borne material, an arrangement with inert plastic net in several layers (Fig. 6) was set up in the clearing (C in Fig. 1). Four rain gauges were placed below it.

In spite of approximately equal amounts of rainwater the concentration of nutrients is much higher in the rainwater under the plastic net than in the incident rainfall. This must be explained by

1. A relatively higher precipitation. The arrangement, situated in an open field, showed a considerable edge effect, especially in windy weather, and received more rainwater than the gauges measuring the incident rainfall. However, the interception and the evaporation was also great in the plastic net, which was revealed particularly after small rain showers, and as a result the average amounts of rainwater were about the same.

2. Aerosols sticking to the net.

The ratio between the rainfall under the plastic net and the incident rainfall for different elements (II/I in



Fig. 6. The arrangement with plastic net in a clearing. In the beginning 17 layers of plastic net were used. These were reduced to 10 after a short time to avoid too high an interception.

Tab. 4. Average values in kg/ha of the nutrients in the incident rainfall (I) and in the rainwater under the plastic net (II). Figures in parentheses = 95 % confidence limits.

Date 1968	Precip. type	Precip. quant.	Na kg/ha	K kg/ha	Ca kg/ha	Mg kg/ha	Mn kg/ha	Cl kg/ha	SO ₄ -S kg/ha	PO ₄ -P kg/ha	Tot.-N kg/ha	pH
April 8	Inc. rainfall I	22.8	0.33	0.03	0.23	0.05	<0.001	0.56	0.34	0.85	0.18	5.6
	Below plastic net II	11.1	1.65	0.13	0.83	0.26	0.012	2.55	1.09	3.68	0.55	5.8
May 6	I	22.1	0.03	<0.01	0.09	0.02	<0.001	0.14	0.16	1.09	0.18	4.8
	II	30.7	2.54	0.18	2.02	0.52	0.030	0.33	2.96	9.61	1.06	5.0
May 20	I	34.2	0.13	0.01	0.05	0.02	0.006	0.17	0.15	1.38	0.10	5.1
	II	56.5	1.03	0.08	0.38	0.16	0.020	1.42	0.75	3.50	0.36	4.9
June 19	I	29.0	0.01	0.01	0.17	0.01	0.003	0.21	0.24	2.33	0.31	5.1
	II	31.9	0.21	0.07	0.67	0.08	0.015	0.63	0.99	11.47	0.64	4.8
June 28	I	55.9	0.17	0.07	0.13	0.03	0.009	0.36	0.74	4.33	0.69	5.0
	II	56.0	0.41	0.06	0.30	0.08	0.015	0.67	0.80	11.78	0.95	4.4
Aug. 19	I	28.9	0.17	0.08	0.08	0.04	0.003	0.47	0.15	3.50	0.26	5.7
	II	35.4	2.63	0.27	0.85	0.36	0.011	4.73	0.92	23.16	0.75	4.9
Oct. 11	I	58.1	0.07	0.08	0.13	0.02	0.019	0.16	0.25	3.78	0.32	5.1
	II	53.7	0.05	0.17	0.16	0.07	0.020	0.56	0.57	6.67	0.54	4.9
Nov. 12	I	24.6	0.02	0.01	0.11	0.01	<0.001	0.05	0.12	1.53	0.09	5.8
	II	16.0	0.38	0.04	0.26	0.07	0.008	0.70	0.34	2.13	0.32	5.6
Σ I		276	0.9	0.29	0.99	0.20	0.04	2.1	2.2	19	2.13	5.3
		(±22)	(±0.1)	(±0.06)	(±0.09)	(±0.01)	(±0.02)	(±0.2)	(±0.3)	(±2)	(±0.21)	(±0.1)
Σ II		291	8.9	1.00	5.47	1.60	0.13	11.6	8.4	72	5.17	5.1
		(±29)	(±1.2)	(±0.12)	(±0.03)	(±0.26)	(±0.03)	(±1.6)	(±1.4)	(±16)	(±0.52)	(±0.1)
Ratio II/I		1.06/1	9.6/1	3.5/1	5.5/1	8.0/1	3.3/1	5.5/1	3.9/1	3.8/1	2.4/1	-

Tab. 4) increases in the order N < Mn, K, <P, S, <Ca, Cl, < Mg, Na, which also suggests the relative increase of the occurrence of the elements in the aerosols. To judge from Fig. 7 the higher proportion of hydrogen ions in the rainwater of the spruce forest must derive from leaching. The same holds for potassium

and manganese in both forest types. Magnesium, sodium, calcium and chloride on the other hand, could derive to a great extent from aerosols. Sulphate, being a more dominant anion in the spruce forest than in the beech forest, is probably explained by leaching processes. The relatively high concentration of nitrogen in the incident rainfall and the low value of the nitrogen ratio II/I (Tab. 4), suggests that nitrogen is precipitated mainly in the direct rainfall and not as dry deposition of aerosols in the meantime between the rain showers.

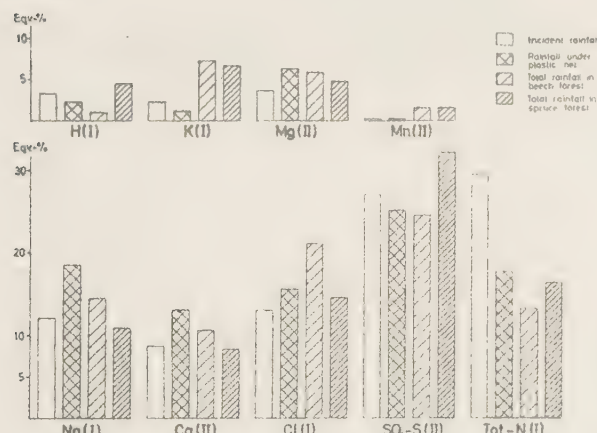


Fig. 7. Bar graphs on the relative proportions of elements in equivalents/ha of the incident rainfall, of the through-fall + stem flow of the beech and the spruce forests and of the rainfall under the plastic net. The figures are calculated on the summed values from twelve sampling occasions, except for the plastic net figures with only eight occasions. Valence values used in parentheses.

9. Conclusions

Great differences exist between the investigated beech and spruce forests concerning the precipitation. In spite of a higher interception and lower rainfall reaching the ground, the amounts of nutrients are higher in the rainwater of the spruce forest than in that of the beech forest. The rainwater is more acid in the spruce forest, especially concerning the stem flow.

Judging from the plastic net experiment and provided that the plastic net has the same adherent capacity as the needles and the leaves, there is no indication of the spruce forest being more aerosol-adherent than the beech forest. The higher amounts of nutrients in the rainwater of the spruce forest thus ought to derive from more pronounced leaching processes of the canopy, probably explained by the presence of alive, dying and dead needles on the branches throughout the year.

The drier soil in the spruce forest compared with the beech forest soil might be explained by the higher interception and probably also by a longer transpiration period in the spruce forest.

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V. PEDOLOGY

Pedological influence of spruce planted on former beech forest soils in Scania, Southern Sweden.

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Abstract

On double localities, with beech and first generation of planted spruce forests situated side by side, the soil conditions were investigated. The most intense studies were made in a special investigation area at Kongalund, less intense at two other special localities and at another 20 double localities. The main observed changes are:

An accumulation of organic matter and a formation of mor in the soil surface of the spruce forest.

A change in some physical properties of the upper soil horizon.

A decrease in the amount of available water in the spruce forest soil and a less transport of rainwater to the underground water.

A decrease in exchangeable K and Ca but an increase in Fe, PO_4 and acid substances in the upper horizon of the spruce forest soil. pH decreased down to at least 50 cm depth.

The nitrification process was reduced and mineralized NH_4 was mobilized to a greater extent in the spruce forest soil than in the beech forest soil.

The changes are discussed from an ecological-pedological point of view and it is concluded that soils with a moderately good mineral composition and without influence from underground water ought to be most seriously damaged by podsolizing effects when they are planted with spruce forests.

1. Introduction

The present paper is part of an investigation elucidating some ecological-pedological changes appearing when spruce is planted on former beech forest soils in Scania. The aims of this part are primarily to illustrate changes in the soil concerning the structural conditions, the availability of water and nutrients, the acid-base conditions and the soil organic matter; secondly to estimate quantitative figures of nutrients and soil organic matter in the root zone, for use in an ecosystem budget (Nihlgård 1970 c) for Kongalund, a special area described earlier (Nihlgård 1969).

Forest soils are inhomogeneous and to get significant results especially when expressed on a volume or area basis, many soil profiles have to be investigated and analysed even within a very small area (cf. Troedsson & Tamm 1969). In this investigation often the demand for statistical significance has had to be abandoned; consequently the obtained changes must then be regarded as indications rather than proved phenomena.

The observations have been performed during 1966 - 1968 and for preference in Kongalund. Also, several analyses have been done in two other localities and the pH measurements derive from several localities.

2. Description of localities

The exploited localities are all composed of one beech forest and one planted spruce forest situated side by side with the same soil textural conditions. It has been proved that the spruce forest is growing on ground formerly covered with beech (cf Nihlgård 1970 a).

The main locality, Kongalund, has been described earlier, but a few data are surveyed below together with the two more extensively used localities situated at Slätteröd and Bökeberg. The situations are given as coordinates according to the topographical map of Sweden, scala 1:50 000.

I. SLÄTTERÖD (situation UB 986536, 2C MALMÖ SO)

Beech forest: Ca. 135 trees/ha. Av.height 27 m, av. tree diameter at breast height (D) 35 cm, 60-100 years old. Estimated crown cover 60 %. Ground vegetation dominated by *Asperula odo-*

rata, *Milium effusum*, *Oxalis acetosella*, *Stellaria holostea*, *Stellaria nemorum* ssp. *glochidosperma*. *Anemone nemorosa* in the vernal aspect.

Spruce forest: Ca. 750 trees/ha. Av. height 23 m, av. D 25 cm, 50 years old. Estimated crown cover of 60 %. Ground vegetation mainly *Oxalis acetosella* and *Rubus idaeus*, covering about 60 % of the ground. The first spruce forest generation.

Soil diagnosis: Acid brown forest soil. Sand - fine sand - silt - clay with dominating fine sand.

To judge from the ground vegetation of the beech forests, this locality ought to have the most favourable conditions to the plants. Probably this is due to the water factor, as the site is situated on a slight slope (inclination 4°).

II. KONGALUND (situation UC 880 068, 3C Hälsingborg SO)

Beech forest: Ca. 240 trees/ha. Av. height 25 m, av. D 39 cm, 60-120 years old. Estimated crown cover of 80-90%. Ground vegetation dominated by *Stellaria nemorum* ssp. *glochidosperma*, *Lamium galeobdolon* and *Oxalis acetosella*. *Anemone nemorosa* in the vernal aspect.

Spruce forest: Ca. 880 trees/ha. Av. height 25 m, av. D 28 cm, 55 years old. Estimated crown cover of 80-90%. Ground vegetation almost lacking, only scattered individuals of e.g. *Oxalis acetosella* and *Rubus idaeus*. The first spruce forest generation.

Soil diagnosis: Acid brown forest soil. Glacifluvial moraine with an equal distribution of grain sizes from stones to clay. See Fig.1.

III. BÖKEBERG (situation UB 925 5 , 2C Malmö SO)

Beech forest: Ca. 125 trees/ha. Av. height 28 m, av. D 40 cm, 60-100 years old. Estimated crown cover of 80 %. Sparse ground vegetation with *Lamium galeobdolon*, *Oxalis acetosella* and *Stellaria holostea*. *Anemone nemorosa* in the vernal aspect.

Spruce forest: Ca. 900 trees/ha. Av. height 20 m, av. D 22 cm, 40 years old. Estimated crown cover of 90 %. Ground

vegetation almost lacking, only scattered *Oxalis acetosella* and *Dryopteris spinulosa*. The second spruce forest generation. Preceded by 90 years old spruce forest.

Soil diagnosis: Acid brown forest soil. Moraine, with sand as the dominating fraction.

Besides twenty other localities were used for description of visible changes in the soil profile and for pH measurements (cf. Nihlgård 1970).

The performed investigations had the following distribution on localities:

	Kongalund (II)	Slätteröd (I)	Bökeberg (III)	Other localities
Soil profile morphology	x	x	x	x
Soil physical properties	x	-	-	-
Soil moisture variation	x	-	-	-
pH	x	x	x	x
Exch. soil nutrients	x	x	x	-
Tot. soil nutrients	x	-	-	-
Soil organic matter	x	x	x	-
Nitrogen mobilization	x	-	-	-

3. Terminology and methods

a. Description of soil profiles

In describing the soil profile the following symbols were used for different horizons:

- A₀₀ - surface litter layer.
- A₀ - humus horizon not entirely integrated with the mineral soil. Usually a mor horizon.
- A₀₁ - (F) horizon with partly unbroken litter material. Brown.
- A₀₂ - (H) horizon with completely broken litter. Black brown.
- A₁ - Humus horizon entirely integrated with the mineral soil. Usually a mull with crumb structure. Black.

- A₀ - leached podsollic mineral horizon, **lacking** integrated humus; whitish colour.
- A₁/A₂ - a horizon considered to be in a transitional stage between A₁ and A₂.
- B₁₋₂ - brown earth illuvial horizon; brownish especially from precipitated iron complexes (B_o); sometimes with an accumulation of leached-in humus in the upper part (B₁).
- (B) - brown earth horizon without notable illuviation. Decreasing humus content downwards.
- C - unweathered or only slightly changed (indifferent) mineral soil.

The following soil types are referred to: podsoils with A₀₀, A₀₁, A₀₂, A₂, B and C horizons, podsoloids (see Linnermark 1960, Nihlgård 1970 a) which show general resemblances to sod-podsolic soils (Kononova 1966 p. 430) and have A₀₀, A₀₁, A₀₂, A₁/A₂, (B)/B and C horizons, Brown forest soils with A₀₀, A₀₁, A₁, (B) and C horizons. The A₀₁-horizon of brown forest soils appears only in acid variants.

In the soil profile diagnosis the soil colour is described according to Munsell Soil Color Charts (1954). L = the percentage loss on ignition of dry soil samples and W = the weight percentage actual water content of fresh soil samples.

b. Soil physical properties

The terminology and methods used on these properties follows, with few additions, Andersson & Ericsson (1963) and Andersson (1970).

The mechanical composition was determined in one profile of both the beech and spruce forest soils in Kongalund from cylinder-samples, 193 and 385 cm³ in size. Three samples from each successive 5 or 10 cm level, down to a depth of 65 cm were taken, as far as possible following different horizons. Dry sieving gave the stone, gravel, sand and coarse fine sand fractions. The hydrometer analysis (Gandahl 1952) on 100 g dry fine earth was used to get the fine sand, silt and clay fractions. The stone fraction was underestimated from the cylinder samples and a correction is made in the mechanical

composition diagrams, according to 10 1 samples taken from corresponding levels.

The soil-moisture characteristics were determined on double samples at the following pF-values:

- pF 0,4 or 0.7 - the water capacity of 5 or 10 cm cylinder samples, after water saturation from below and drainage during one day.
- pF 2,0 - the water storage of cylinder samples after drainage on a suction bed at a suction pressure of 100 cm of water.
- pF 3,2 - the water storage of fine earth in a special pressure pot (Soil Moisture Equipm. Comp., USA) fitted with plaster plates. Oxygen pressure 1.5 Atm.
- pF 4,2 - the water storage of fine earth in a pressure chamber at 15 Atm. (Andersson & Ericson op. cit.)
- pF 6,0 - the hygroscopicity of fine earth in air-evacuated desiccators with 43 % H_2SO_4 .
- pF 7,0 - the water storage after drying at 105°C.

Using pF-curves (pF plotted against percentage water of the dry weight) the actual water storage can be transformed to pF-values. The results are interpreted in the following way: the pF-range < 0.7 indicates excess water, pF 0.7 - 2.0 indicates drainable water, i.e. water that would disappear at drainage (= field capacity), pF 2.0 - 3.2 holds water that is easily available to plants, pF 3.2 - 4.2 holds water that is not so easily available to plants and the range pF 4.2 - 7.0 holds water that is usually regarded as unavailable to plants.

Loss on ignition (L) was determined at about 550°C. Specific gravity (s) was determined on fine earth by 96 % alcohol to a known amount of soil until 50 ml volume was reached. The permeability (k-value) was estimated by water percolation on cylinder samples.

Calculations to get bulk density in undisturbed stratification, dry bulk density, material volume and pore space follow Andersson & Ericson 1963.

The soil-moisture variation (0-65 cm depth) was studied for a whole year in both the beech and the spruce forest stand of Kongalund. Five soil cores were randomly sampled each month within each stand by a steel auger (diam. 22 mm). The water

content (105°C) was determined gravimetrically on each ten cm. This gave the actual water storage, the values of which were first transformed to percentage volume and then to pF-values. The error, including natural variation and expressed as 95% confidence limits on the total material, is estimated to $\pm 7\%$ for the volumetric soil moisture values. Error in the determination of the water content (vol.-%) at different pF-values, varies between ± 3 and $\pm 8\%$ as calculated on duplicated samples. This implies a maximum error of the pF on the soil moisture variation of $\pm 15\%$.

c. Chemical analyses

For chemical analyses 5 or 10 cm cylinder samples were taken down to 55 or 65 cm depth and analysed in fresh or dry condition. Three profiles from both the beech and the spruce forest soils in Kongalund (II) and two profiles from each forest type in Slätteröd (I) and Bökeberg (III) were investigated. The samples were weighed and sieved to get the fresh fine earth ($< 2\text{ mm}$) on which the chemical analyses were performed. For total analyses the soil was dried at 85°C .

The reduced wet and dry bulk densities, i.e. reduced with the weight of mineral and organic material coarser than 2 mm, of each individual samples was used to transform the analyses to a volume or area basis.

pH was determined electrometrically (pH-meter type Beckman N-2, accuracy ± 0.02) on fresh soil samples, both in extracts of water and of 0.2 M KCl after sedimentation in 12 hours. Extraction time two hours, volume proportion soil: solution was 1:2.

Exchangeable hydrogen ions were determined in equilibrium extracts of 1 M NH_4Ac as the change of pH (measured by pH-meter type Beckman Expandomatic). See Brown 1943, Andersson 1970. 10 - 30 g fresh soil were used per 100 ml NH_4Ac . Extraction time two hours.

Exchangeable Na, K, Ca, Mg, Fe, Mn and S were determined after equilibrium extraction in 1 M NH_4Ac as above. The metallic cations were analysed on Perkin Elmer Atomic Spectrophotometer 303 after dilution (30 ml extract to 100 ml solution). Exchangeable S was determined after evaporation of 10-20 ml extract at 105°C with H_2O_2 p.a. A turbidimetric method was used (Bardsley & Lancaster 1960).

Carbon (C) was determined on dry fine earth (85°C) by a wet

combustion method (Jansson & Waldmaa 1961, p.309).

Total nitrogen (tot.-N) was determined on dry fine (85°C) earth by a semimicro Kjeldahl method (Andersson 1970, p.145).

Exchangeable PO_4 was determined in acetate-lactate (AL) extracts (Egner et al. 1960),

Exchangeable NO_3 -N was determined in HAC extracts according to Bray 1945 (Method 1, Procedure 1). 10 g soil per 50 ml solution were used.

Exchangeable NH_4 -N was determined in 0.2 M KCl extracts by the Nessler method (Jackson 1958, p.194-196). 10g soil per 50 ml solution were used.

Exchangeable Al was determined according to Yuan (1959 p.164), in equilibrium extracts of 1 M KCl.

Total elemental analysis was performed on dry fine earth using a HCl - HF treatment according to Pawluk 1967 (cf. Andersson 1970 p.146). Metal cations were determined as above (Ca and Mg in a 1% La-solution). Al was determined with Yuan's method (op.cit.).

Percentage exchangeable metal ions, or Me-saturation were calculated as the sum of Na, K, Ca and Mg equivalents (=Me) divided by Me + exchangeable hydrogen ions (H): $\frac{\text{Me} \cdot 100}{\text{Me} + \text{H}}$.

The analytical errors, as estimated from duplicated samples, were of the order of ± 1 -10%, while the natural variation between different soil profiles was of the order of ± 5 -50% or even more in the upper horizons. To reduce the variations a composite sample (n=15) of the surface horizon (0-2 or 3 cm) was also collected and analysed. The results from this are also given in the diagrams, unless they were identical with those from 0-5 cm or unless their figures were too high to be easily included in the diagrams. In the latter case the results are indicated by extended lines.

4. Visible changes in the soil profile

A few remarks can be made on the results given in Table 1 and Table 2 (profiles 1-14). The A_{00} (surface litter) layer is very loose in the beech forest while it is compact in the spruce forest. At equal height in cm therefore the amount of litter expressed in weight/area (ton/ha) can be three times greater in the spruce forest (cf. Table 5).

Table 1.

A survey of the thickness of the litter layer, of the A_0 or A_1 horizons and indications of the development of A_2 and B_2 horizons in the soil of the investigated double localities. The stands are arranged after increasing age at breast height of the spruce forest (as estimated from boring with an increment borer). The last stand was preceded by a 90-years old spruce forest. The descriptions were performed during the summer period.

Age (years)	Thickness (cm) of				Indications ^{a)} of			
	A_{00} -layer		A_0/A_1 -horizon		A_2 -horizon		B_2 -horizon	
	Beech	Spruce	Beech	Spruce	Beech	Spruce	Beech	Spruce
26	3	1	3/2	5/0	0	+	0	0
32	3	3	2/9	2/3	0	0	0	0
35	5	3	2/2	3/3	0	0	0	0
35	3	2	0/10	1/9	0	0	0	0
37	4	4	0/2	5/0	+	++	+	+
38	4	4	4/0	5/0	+	++	+	+
40	3	3	2/9	2/5	0	+	0	0
40	3	3	0/13	0/3	0	0	0	0
40	4	3	1/6	3/2	0	+	0	0
45	2	2	0/7	2/2	0	+	0	+
47	2	3	1/2	3/2	+	++	+	++
48	4	3	1/5	3/3	0	+	0	0
50	3	3	1/10	2/2	0	0	0	0
51	3	3	0/4	3/0	0	+	0	0
52	5	3	3/2	7/2	+	++	+	+
56	5	2	2/2	2/1	+	+	0	0
57	3	3	2/5	9/0	+	++	++	++
60	4	2	1/7	8/0	0	++	+	++
62	4	3	4/10	6/1	0	+	0	0
70	4	3	3/3	12/0	+	++	+	+
70	3	3	0/10	5/8	0	+	0	0
80	3	1	2/4	8/0	++	++	+	++
40(+90)	3	3	0/6	3/0	0	++	0	+

a) 0 = no indication
 + = slight indication
 ++ = strong indication

Table 2. Description of the soil profiles (1-14) from Slätteröd, Kongalund and Bökeberg.

Profiles 1-2. The beech forest soil, Slätteröd. Sampling day:
29.7.1967.

Diagnosis:

- 3-0 cm - A₀₀ Surface litter layer. Leaves and twigs. Very loose.
- 0-0.5 cm - A₀₀ Thin organic horizon of slightly decomposed leaves.
- 0.5-6 cm - A₁ Mull horizon. Dark brown (7.5 YR 3/2). Sand - clay. Medium crumb structure. Rich in roots of herbs and beech. L = 9.5 %, W = 19 %.
- 6-10 cm - B₁ Transitional horizon. Brown (7.5 YR 4/2).
L = 6.3 %, W = 17 %.
- 10-40 cm - (B) Brown earth horizon. Brown (7.5 YR 4/4). Sand, fine sand (dominating), silt and clay. A few stones. Beech roots evenly distributed. A hard and dry horizon.
L = 4 %, W = 11 %.
- 40-70 cm - C Indifferent horizon. Ground colour light brown to pink (7.5 YR 5/4 - 7/4). Oxidized reddish brown. Ferric aggregates are usual. Very hard. Very few beech roots.
L = 1.5 %, W = 7 %.

Profiles 3-4. The spruce forest soil, Slätteröd. Sampling day:
29.7.1978.

Diagnosis:

- 3-0 cm - A₀₀ Surface litter layer. Needles and twigs. Compact.
- 0-2 cm - A₀₁ Mor-like horizon of partly decomposed needles. Rich in small spruce roots.
- 2-7 cm - A₁ Degraded mull horizon. Fine crumb structure. Dark brown (7.5 YR 3/2). L = 5 %, W = 12 %.
- 7-12 cm - A₁/A₂ Transitional zone. Light brown (7.5 YR 6/4). Loose and dry. Obvious indications of leaching.
L = 4 %, W = 10 %.
- 12-40 cm - (B) Brown earth horizon. Cf. profiles 1-2.
Brown (7.5 YR 5/4). Only a few spruce roots.
L = 3 %, W = 8 %.
- 40-70 cm - C Indifferent horizon. Cf. profiles 1-2.
L = 1.5 %, W = 6 %.

Table 2 cont.

Profiles 5-7. The beech forest soil, Kongalund. Sampling days:
29.6. - 11.7.1967. Cf. also Figs. 1-2.

Diagnosis:

- 3-0 cm - A₀₀ Surface litter layer. Leaves and twigs. Very loose.
- 0-1 cm - A₀₁ Thin organic horizon with slightly decomposed leaves. Rich in roots especially *Lamium galeobdolon*.
- 1-7 cm - A₁ Mull horizon. Black (5 YR 2/1). Crumb structure. Earthworms. Rich in root stems of *Anemone nemorosa* in the upper cm, and several fine beech roots.
L = 20 %, W = 35 %.
- 7-30 cm - (B) Brown earth horizon. Dark brown - dark reddish brown. (7.5 YR 3/2 - 5 YR 3/4). Rich in beech roots.
L = 10 %, W = 25 %.
- 30-50 cm - (B)/C Transitional horizon. Brown (7.5 YR 4/4). Relatively hard and stony horizon with several beech roots.
L = 4 %, W = 18 %.
- 50-70 cm - C Indifferent horizon. Light brown (7.5 YR 5/4). Very hard and compact. Roots sparse. L = 2.5%, W = 12%.

Profiles 8-10. The spruce forest soil, Kongalund. Sampling days:
30.6 - 14.7.1967. Cf. also Figs. 1-2.

Diagnosis:

- 3-0 cm - A₀₀ Surface litter layer of needles and twigs. Compact.
- 0-3 cm - A₀₁ Decaying horizon. Pure organic with needles and pegs slightly kept together by fungus mycelium. Several fine roots of spruce with mycorrhiza. Dark brown.
- 3-4 cm - A₀₂ Humus horizon with almost completely decomposed organic material. A small mineral fraction. Dark reddish brown (5 YR 2/2). Rich in fine roots of spruce with mycorrhiza.
- 4-10 cm - A₁/A₂ Degraded mull horizon with indication of a leached A₂-horizon in the upper part. Grayish brown - dark brown (7.5 YR 5/2 - 7.5 YR 3/2). Rich in spruce roots.
L = 9 %, W = 25 %.
- 10-30 cm - (B) Brown earth horizon. Dark reddish brown (5 YR 3/5-3/4). Indication of a higher humus content at about 15 cm depth with a darker colour. Spruce roots relatively sparse. L = 6 %, W = 19 %.
- 30-50 cm - (B)/C Transitional horizon. Cf. profiles 5-7. spruce roots sparse. L = 4 %, W = 16 %.

Table 2 cont.

50-70 cm - C Indifferent horizon. Cf. profiles 5-7. L = 2.5 %, W = 12 %.

Profiles 11-12. The beech forest soil, Bökeberg. Sampling days:
21.7 - 22.7.1967.

Diagnosis:

3-0 cm - A₀₀ Surface litter layer. Leaves and twigs. Very loose.
0-1 cm - A₀₁ Thin organic horizon with slightly decomposed leaves.
1-6 cm - A₁ Mull horizon. Dark gray - dark reddish brown (5 YR 3/2). Fine crumb structure. Earthworms. Sand - fine sand are the dominating texture fractions. Rich in herb roots and fine roots of beech. L = 8%, W = 18%.
6-30cm-A₁/(B) Brown earth horizon. Brown (7.5 YR 5/4). Rich in beech roots. L = 2 %, W = 6 %.
55-80 cm - C Indifferent horizon. Light brown (7.5 YR 6/4). Moraine with stones, gravel, sand and fine sand. In several places very compact and hard. L = 1 %, W = 4 %.

Profiles 13-14. The spruce forest soil, Bökeberg. Sampling day:
22.7.1967.

Diagnosis:

3-0 cm - A₀₀ Surface litter layer. Needles and twigs. Compact.
0-3 cm - A₀₁₋₀₂ Mor horizon. More or less decomposed needles. Black - dark brown. Several fine spruce roots with mycorrhiza.
3-8 cm - (A₁) Degraded mull horizon with obvious leaching indications. Sand dominates. Dark brown - brown (7.5 YR 4/4). L = 7 %, W = 14 %.
8-25 cm-A₁/A₂ Transitional zone with obvious leaching indications. Brown (7.5 YR 5/4). Stony. Sand and fine sand dominate. A few spruce roots. L = 4 %, W = 12 %.
25-45 cm -B/(B) Brown earth horizon with obvious illuvial precipitation features. Strong brown (7.5 YR 5/6). A few spruce roots, L = 3 %, W = 11 %.
45-80 cm - C Indifferent horizon. Cf. profiles 11-12. L = 1.5 %, W = 7 %.

The humus rich A_1 horizon ought to be an obvious mull, with intimately mixed organic and inorganic fractions. However, in Table 1 transitional stages, mor-mull (cf. Nihlgård 1970 a). are also included in the A_1 designation.

The main conclusions that can be drawn from the descriptions are:

- a. The surface litter layer has not changed into a thicker layer - the opposite can be the case - but as the spruce forest litter is much more compact it has certainly increased in weight in most stands (cf. Table 5).
- b. The biologically active A_1 horizon, usually found in the beech forest soils, has degenerated and often got the character of, or an indication of, a leaching horizon (A_2) in the spruce forest soil. An A_0 (mor) horizon has usually developed above the former A_1 -horizon, unless the latter was very large when it would probably also have a high decomposition capacity. If an A_0 horizon already existed in the beech forest soil, it was enlarged under the influence from spruce. The formed soil type can often be referred to as a podsoloid.
- c. In some soils with an obvious change into an A_2 horizon an indication of or an increase of a B_2 (precipitation) horizon is also found.
- d. The degenerated characters are most obvious in soils of old spruce forest stands.

5. Changes in soil physical properties

In the comparisons between beech and neighbouring spruce forests, it is assumed that the soil textural compositions are alike. This has usually been confirmed from field observations, but in the main investigated locality, Kongelund, it has also been checked by textural analyses from one soil profile of each stand (Fig. 1 A-D).

There is a slightly higher percentage gravel in the beech forest soil, but this difference probably only reveals the inhomogeneity of the ground and is not typical for the stands. The loss on ignition, on the other hand, certainly shows a significant trend with accumulation of organic matter in the soil surface of the spruce forest.

The specific gravity and the dry bulk density (Table 3) are

Fig.1 A - D. Textural composition of the beech forest soil (A and C) and the spruce forest soil (B and D) at Kongalund.

A and B show the composition of the total soil, C and D the composition of the fine earth ($< 2\text{mm}$).

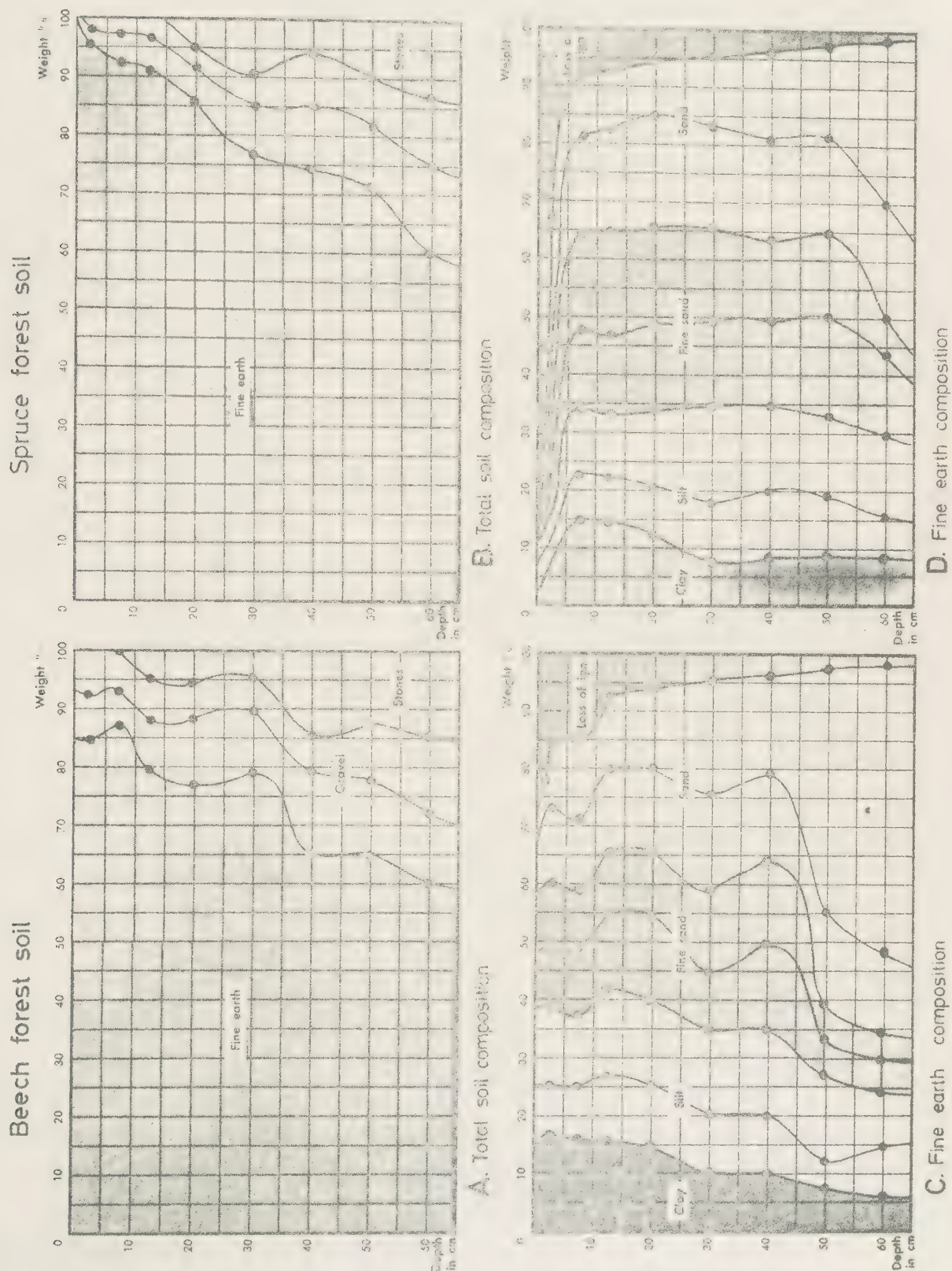


Table 3. Some soil physical properties from the beech and the spruce forest soils in Kongalund. The variation range from duplicated samples (of s and k) or from tripled samples (bulk density) are given in parentheses.

Depth cm	Spec. gravity, s g/cm ³		Bulk density, g/cm ³				Permeability, k cm/tim	
	Beech	Spruce	Dry (105°)		At water capacity		Beech	Spruce
0 - 5	2.26 (±0.03)	1.60 (±0.15)	0.77 (±0.02)	0.29 (±0.07)	1.40 (±0.04)	0.90 (±0.09)	2.2 (± 1.5)	9.3 (± 1.2)
5 -10	2.36 (±0.04)	2.08 (±0.18)	1.03 (±0.03)	0.38 (±0.03)	1.60 (±0.06)	1.44 (±0.01)	0.4 (± 0.3)	13.1 (± 1.6)
10-15	2.42 (±0.11)	2.25 (±0.04)	1.17 (±0.10)	1.00 (±0.04)	1.69 (±0.09)	1.56 (±0.06)	0.8 (± 0.3)	10.9 (± 2.0)
15-25	2.35 (±0.05)	2.36 (±0.05)	1.18 (±0.02)	1.10 (±0.05)	1.63 (±0.01)	1.52 (±0.04)	12.7 (± 5.5)	14.0 (± 3.4)
25-35	2.34 (±0.02)	2.36 (±0.07)	1.31 (±0.06)	1.12 (±0.01)	1.72 (±0.05)	1.57 (±0.02)	13.2 (± 4.4)	31.3 (± 4.6)
35-45	2.46 (±0.06)	2.36 (±0.05)	1.41 (±0.11)	1.31 (±0.06)	1.74 (±0.04)	1.69 (±0.04)	20.5 (± 3.7)	36.0 (± 5.2)
45-55	2.61 (±0.08)	2.56 (±0.04)	1.55 (±0.04)	1.46 (±0.05)	1.84 (±0.04)	1.31 (±0.04)	44.6 (±11.2)	10.4 (± 1.1)
55-65	2.50 (±0.03)	2.41 (±0.03)	1.54 (±0.00)	1.63 (±0.17)	1.86 (±0.02)	1.95 (±0.12)	28.4 (± 1.1)	16.1 (±14.8)

also equal, except for in the upper horizons where the values of the spruce forest soil are lower. Conversely the permeability is higher in the upper horizons of the spruce forest soil.

The porosity has increased and the retention of water at pF 2.0 is lower (Fig. 2) in the upper horizon of the spruce forest soil. These changes are certainly linked with the structure and feature of the accumulated organic matter. Otherwise there are few and only small differences in the soil water characteristics presented in Fig. 2.

6. Changes in soil moisture variation

The yearly variation of soil moisture in the Kongalund stands was described in volumetric values in connection with the precipitation (Nihlgård 1970 b). Here it is treated in terms of pF, i.e. approximately showing the availability of water to plants (Fig. 3, cf. p.7).

The water conditions can be regarded as sufficient in both forest soils from the plants point of view. However, there is obviously less water available in the spruce forest soil throughout the year. In the beech forest soil there are several occasions with excess water, indicating some support to the underground water. This excess water is absent in the spruce forest soil. Cf. Stålfelt (1944) who found that in the moraine soil of a 40-years old planted spruce forest in northeastern Scania, the rainwater support to the root zone (below the upper 20 cm of the soil) was 0-5% during the growing season (May-August) and 0-25% during the rest of the year. At a depth of 70-100 cm the rain water support completely failed.

7. Changes in soil chemistry

a. Exchangeable elements. The amount of exchangeable elements showed great variations, even between the different profiles within the same stand. Nevertheless several differences between the beech and spruce forest soils were found, but these were not always clearly biased (Fig. 4).

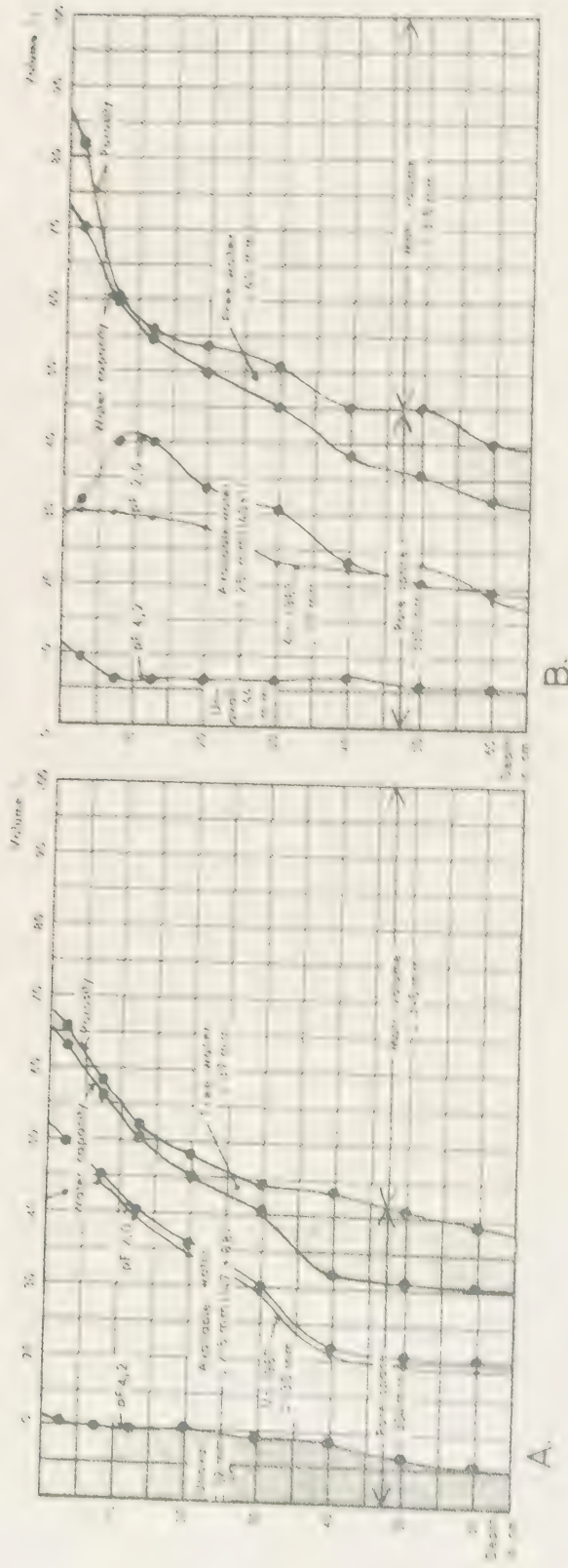


Fig. 2 A-B. The variation with depth of some soil water characteristics of the spruce forest soil (A) and the spruce forest soil (B) at Kongalund.

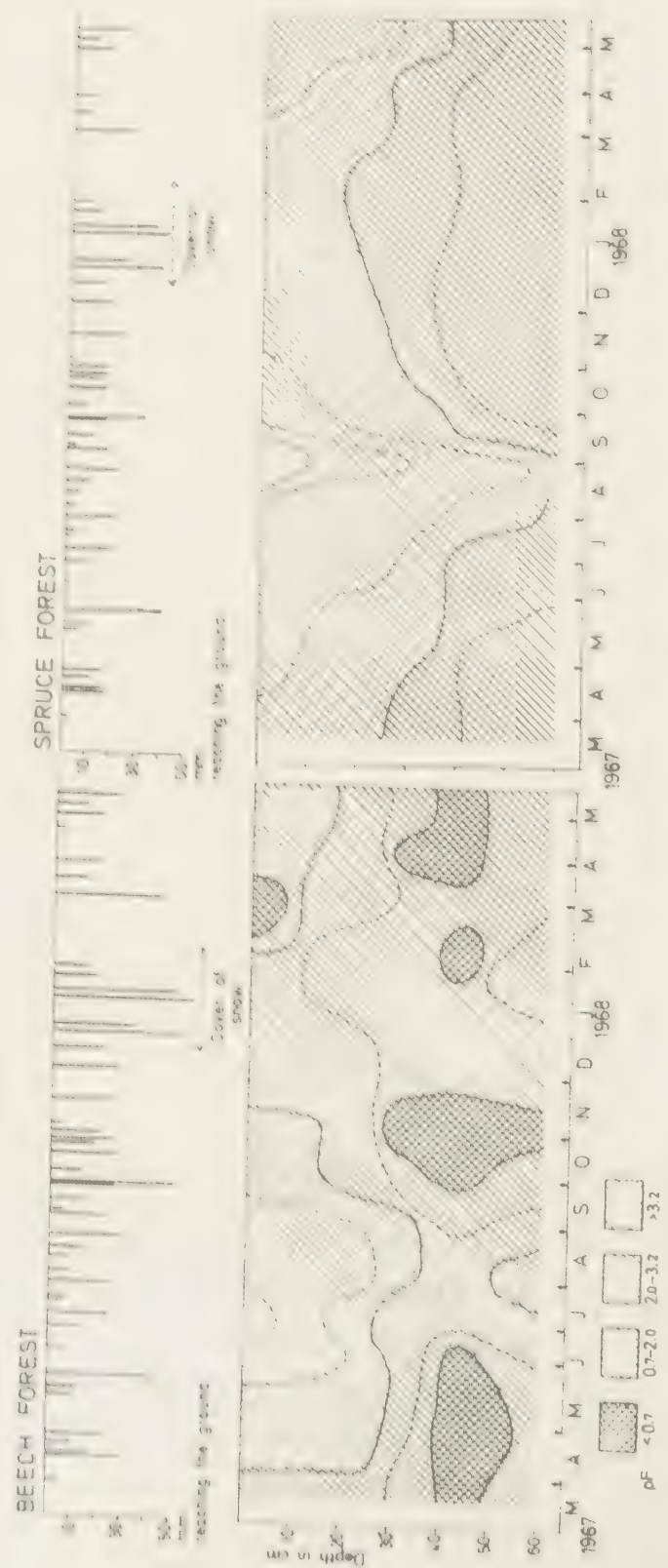


Fig. 3. Landscape diagram showing the variation of the soil moisture down to 60 cm depth expressed in pF-values of the beech and the spruce forest soil at Kongalund. Precipitation reaching the ground is given above.

The most obvious differences, interpreted as changes occurring since the spruce plantation, were:

1. A decrease in the upper horizons and an increase in the lower horizons of K.
2. A decrease of Ca in the upper horizons.
3. An increase of Fe in the upper horizons.
4. An increase of PO_4 in the upper horizons.

Moreover, there was indication of less Mg in the upper horizon and higher amounts of S. The latter was particularly so in Kongalund.

b. Acid-base conditions. Changes in the parameters included in this designation were obvious (Fig. 4, Exch. H, pH, Me-sat.):

5. An increase of exchangeable H, at least in the upper horizon.
6. A decrease in pH, most notable in the upper horizons but observable also at lower depth, especially in H_2O -extracts (= the highest figures in the pH-diagrams).
7. A decrease in the percentage metal cation saturation (Me - sat.).

The lowering of pH in spruce forest soils is also confirmed in the following survey, comprising results of three horizons from 23 double localities. Average values of the pH-difference between the soils from the beech and the spruce forests situated about 50 m apart, are given with 95 % confidence limits.

	pH KCl-extracts	pH H_2O -extracts
A_0/A_1 -hor. (0-5 cm)	0.46 ± 0.13 (n = 23)	0.50 ± 0.15 (n = 23)
A_1/A_2 -hor. (5-10cm)	0.28 ± 0.07 (n = 23)	0.44 ± 0.11 (n = 23)
B/C-hor. (45-50 cm)	0.07 ± 0.03 (n = 23)	0.24 ± 0.03 (n = 23)

The changes are most noticeable in H_2O -extracts, which is explained by the fact that these pH-values are 0.5 - 1.0 units higher, and thus are influenced to a greater extent by even slight increases in acid substances. They also indicate that the acid substances in the spruce forest soils are less

Fig.4.

The variation with depth of some chemical features of the beech and the spruce forest soil at Slätteröd (=I), Kongalund (=II) and Bökeberg (=III). The variation ranges, obtained from values of different profiles, are indicated by thin horizontal lines. Circles and continuous lines refer to the beech forest soils, triangelns and dotted lines refer to the spruce forest soils. Differences indicating higher values in the spruce forest soil are blackened, differences indicating lower values in the spruce forest soil are hatched. In the pH-diagrams the highest figures refer to pH measured in H₂O-extracts; the other are measured in KCl-extracts.

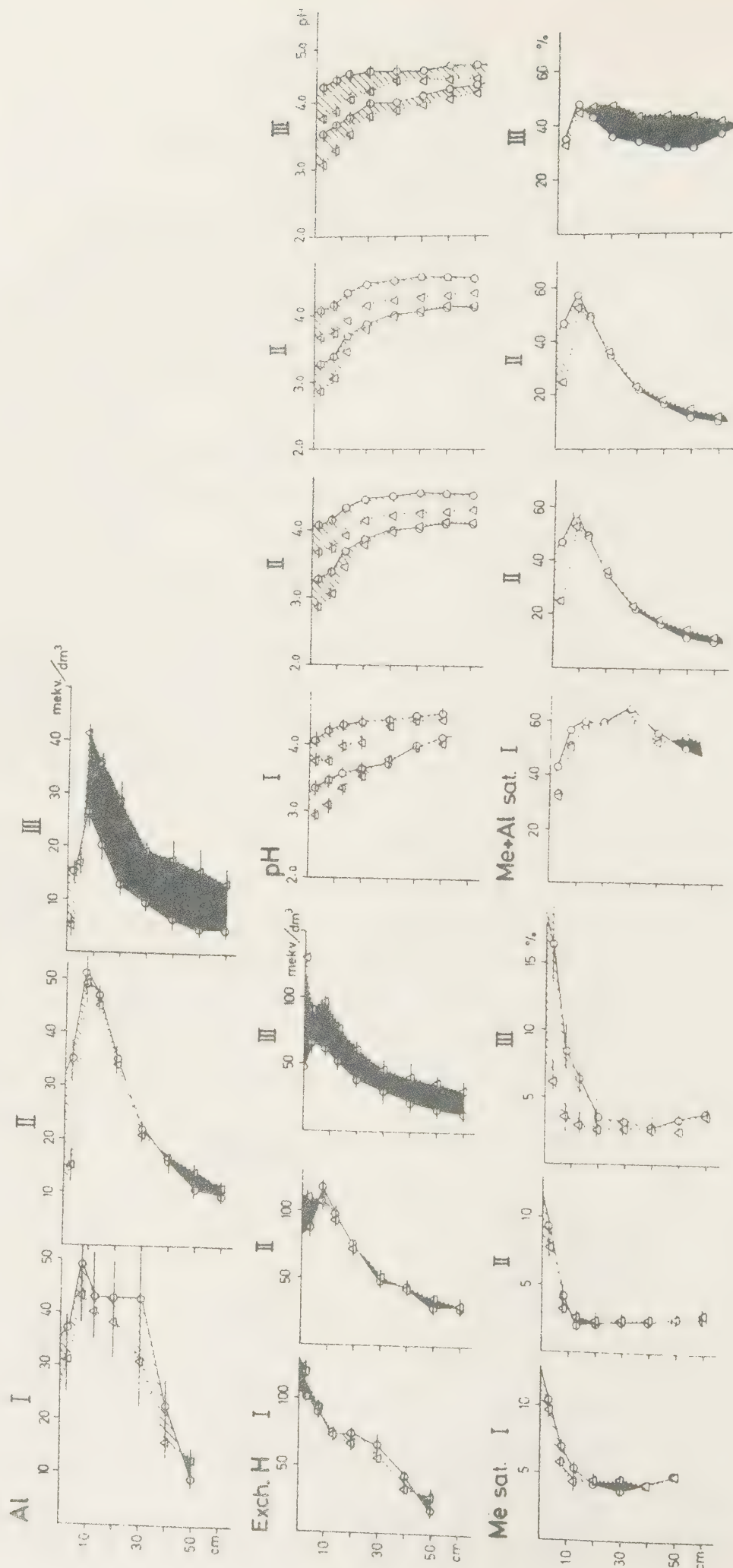
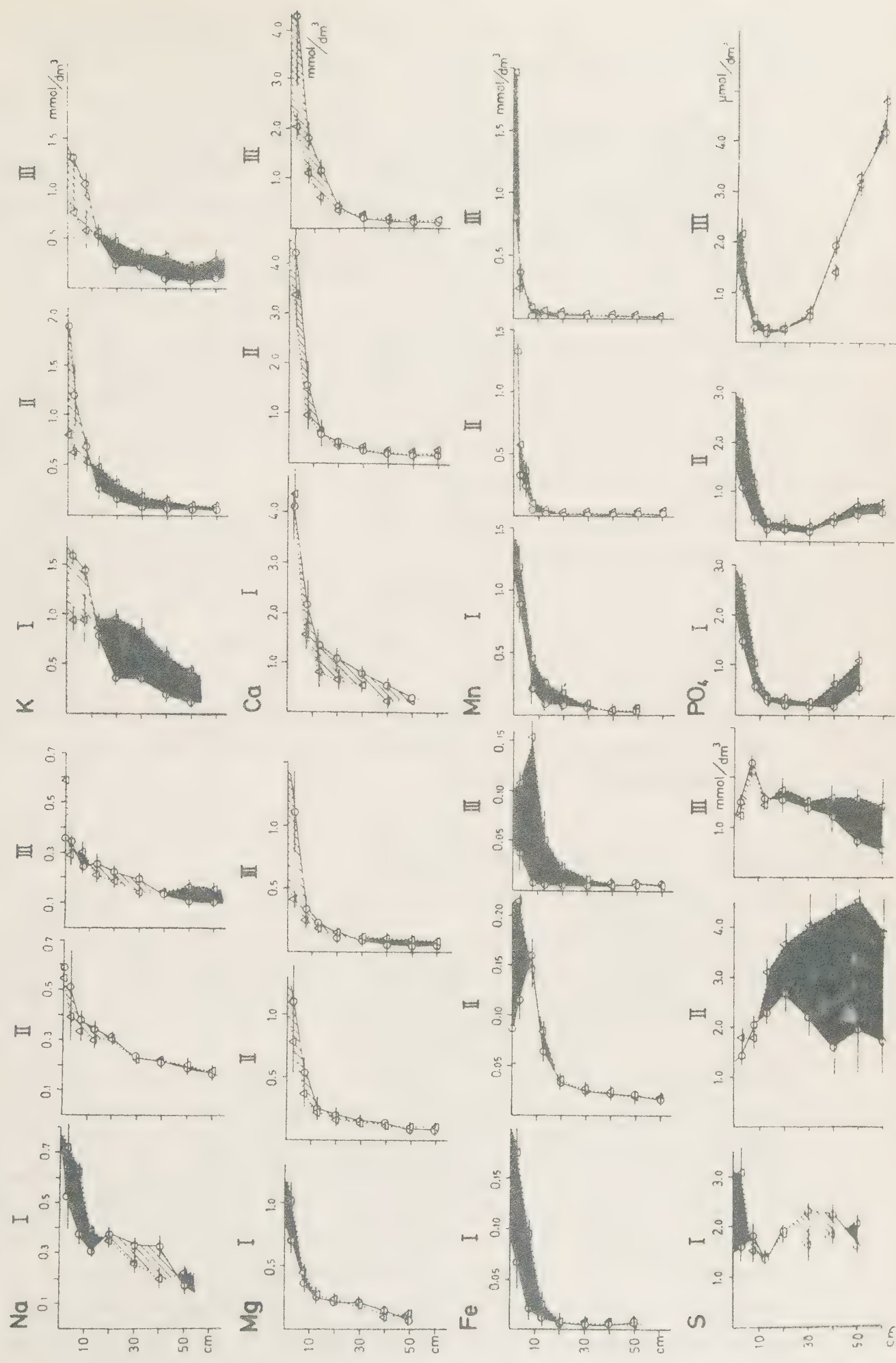


Fig.4, cont.



bound to flocculated colloids and mainly appear in the soil water. This becomes more obvious with depth in the profile.

Al is the most important exchangeable ion in these acid soils (Fig. 4, Al). Al has important buffering properties in the pH-range 4.1 - 5.5 (Pionke & Corey 1967), and in the determination of Exch. H, Al is included as H-ions owing to hydrolyses when pH is raised to almost 7.0 in the NH_4Ac -extract. However, Al is not included as a metal cation in the calculation of Me-sat., but doing so (Fig. 4, Me+Al-sat.) considerably higher saturation figures and improved correlation with pH were obtained. A correlation between pH and Me-sat. is shown to exist at least in soils rich in organic matter (Mehlich 1942, Sjörs 1961, Schachtschabel & Renger 1966).

c. Total amount of mineral elements

The total analysis revealed very similar conditions concerning different elements of the beech and the spruce forest soils in Kongalund. Exception must be made for the upper horizons, where owing to the high organic content the values of the spruce forest soil were pervadingly lower. The summed figures down to 65 cm depth, are surveyed in Table 4, together with the low values of corresponding exchangeable amounts. The latter, expressed as percentage of the total, decrease in the order $\text{Al} > \text{Mn} > \text{Mg} > \text{Ca} > \text{Na}$, $\text{K} > \text{Fe}$.

3. Changes in soil organic matter

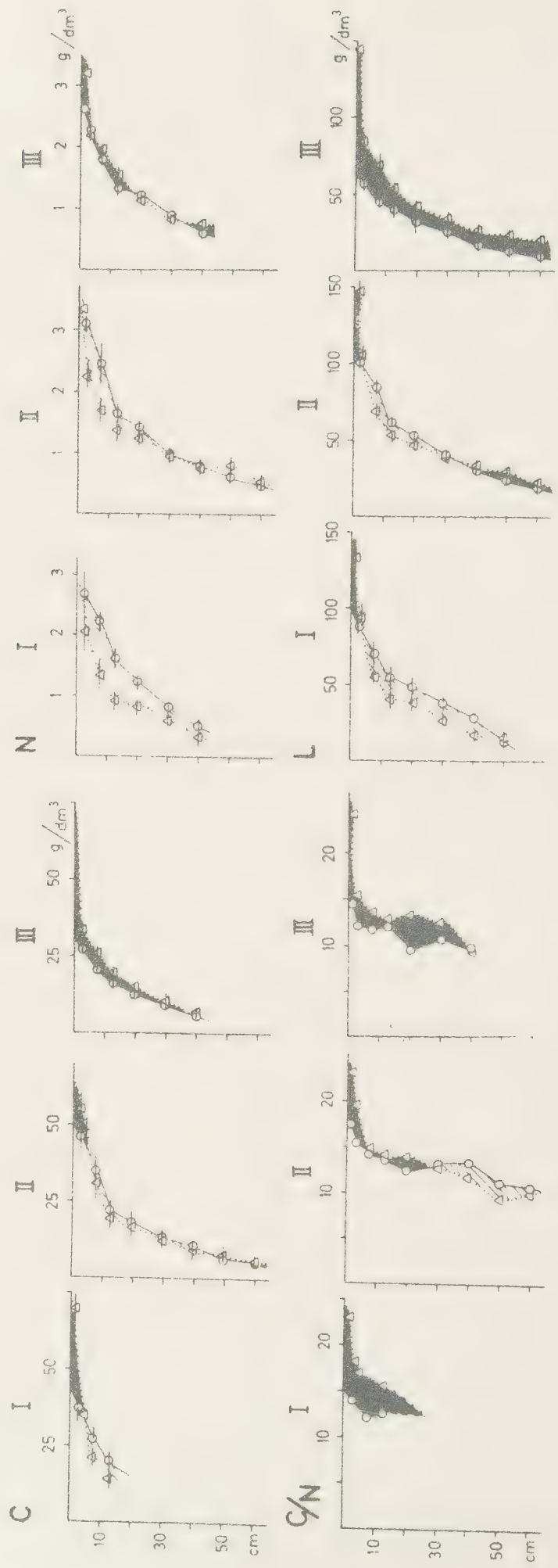
The organic matter is treated in terms of carbon, nitrogen and loss on ignition (Fig. 5). Differences between the beech and the spruce forest soils are small, but pervading trends are the lowering of the nitrogen content and the higher C/N-ratio of the spruce forest soils.

Loss on ignition (L) can be used as a rough estimate of the organic matter, but it is difficult to correct for weight losses resulting from the escape of constituent water (Silverberg 1957) and it would be better to use the carbon content and a "carbon factor". However, the conventional factors 1.72 - 1.78 were rejected and an average carbon factor of 2.0 (range 1.94-2.13) was taken from the ratio litter/carbon (Table 5). This factor was also in agreement with the ratio L/carbon of the soil surface samples (0-2 or 3 cm). It is also in agreement with factors reported by Howard (1966).

Table 4. Total and / exchangeable amounts of nutrients down to a depth of 65 cm in the beech and spruce forest soils of Kongalund. The variation range, as obtained from different profiles within the same stand, is on average $\pm 10\%$.

	Na	K	Ca	Mg	Fe	Mn	Al
				mmol/dm ²			
Beech forest soil	2700/1.71	3100/1.44	2800/4.37	960/1.55	2700/0.26	63/0.19	6200/54
Spruce forest soil	2700/1.65	3400/1.65	3400/3.75	940/1.28	2400/0.28	76/0.26	8000/51
ton/ha = 10 ³ · kg/ha							
Beech forest soil	62/0.039	120/0.056	112/0.175	23.3/0.038	151/0.014	0.35/0.010	168/1.45
Spruce forest soil	62/0.038	130/0.065	136/0.150	22.9/0.031	134/0.016	0.42/0.014	216/1.38

Fig.5. Some organic matter features of the soil in the Kongalund stands.
 C = carbon, N = nitrogen and L = loss on ignition.
 Further legends see Fig.4 .



The following survey is a summary of the organic matter features of the soils in Kongalund.

	Beech forest soil	Spruce forest soil	
	0 - 15 cm		
Carbon	51.3	42.4	ton/ha
Nitrogen	3.6	2.7	"
C/N-ratio	14.2	19.4	"
Soil org. matter (C x 2)	103	105	"
" " " (L)	127	113	"
	0 - 65 cm		
Carbon	103.4	103.4	"
Nitrogen	7.8	6.9	"
C/N-ratio	13.3	15.0	"
Soil org. matter (C x 2)	207	207	"
" " " (L)	298	287	"

Half of the organic matter is thus situated in the upper 15 cm. Though the L-values are corrected for weightlosses of constituent water according to Ekström (1927), they probably give an overestimation of the organic matter especially at lower depth (cf. Howard 1966).

The accumulation of organic matter in the superficial part (0-5 cm) of the spruce forest soil, as indicated by the carbon and loss on ignition values (Fig. 5), is accentuated by the accumulation of litter (cf. p.10). At Kongalund the litter layer of the spruce forest has increased by 350 %, compared with the beech forest (Table 5). The higher C/N-ratio is also obvious.

9. Changes in the mobilization of nitrogen

The accumulation of organic matter in the soil surface of the spruce forest, demanded investigations on the decomposition conditions, on the biological soil activity.

Experiments were made particularly on the nitrogen mobilization in the field during different seasons of 1967 -68.

Composite (n = 15, randomly collected) cylinder soil samples

were taken from the upper 3 cm of the beech and the spruce forest soils. The soil was passed through a 6 mm sieve to become homogeneous. 9 - 12 weighed soil samples in petri dishes covered with watch glasses were placed below the litter. The watch glasses were 12 cm in diameter and were fitted with pieces of foam rubber to allow air circulation. Three samples were removed for analysis after 5, 12, 26 and 46 or 48 days. Before analysis the weight was controlled and if drying had occurred distilled water was added to get the same volume weight as at the beginning. The soil temperature was followed by temperature recorders (see Nihlgård 1969).

The results (Fig. 6) showed obvious connections between the mobilization and the temperature (cf. Mork 1938). Even high maxima-temperatures (Spring 1967) had an increasing effect on the summed nitrogen mobilization. In summer the temperature was high and so also the mobilization rate. During autumn 1967 the processes stopped almost completely when the temperature fell below a "critical" temperature of 4-5°C. In spring 1968 the processes started slowly after the temperature had risen above this critical temperature. The mobilization of NH_4 was obviously most sensitive to low temperatures and was influenced already at temperatures around 10°C.

During the mineralization processes primarily formed NH_4 is transformed to NO_2 or NO_3 by different microbes, (nitrification). In both forests soils there was a mobilization of both NH_4 and NO_3 which shows that all NH_4 was not transformed to NO_3 . This was most apparent in the spruce forest soil, where during the summer experiment 80 % of the mobilized nitrogen consisted of NH_4 . In the beech forest soil the corresponding figure was 63 %. A high amount of NH_4 is typical for mor soils (cf. Hesselmann 1915, Schönhar 1955).

According to the temperature measurements described in Nihlgård 1969, the above results suggest a total mineralization period of about six months during a year. A rough estimate of the mineralization rate from the curves during different seasons, gave the results shown in Table 6. Approximately equal amounts of nitrogen, 100 kg/ha, were released in both soils in the upper 3 cm of the soil profile. This is 12-13% of the total amount of nitrogen in the same layer (Table 6), but it is much more than 100% of the yearly supply of nitrogen from the litterfall. The latter brings 60-70 kg/ha/year to the ground (Nihlgård, 1970 c).

Fig.6. Results of the nitrogen mobilization experiments in the field during different seasons of 1967 and during spring 1968. NO_3 includes NO_2 . Temperature diagrams, obtained from average daily temperatures of the upper soil horizon just below the ground litter, are also given. The temperature of the spruce forest soil is marked with dotted lines and that of the beech forest soil with continuous lines. Maximum and minimum values are indicated by thin vertical lines of each ten day. The temperature area above 4°C is hatched and the lower temperature area of the spruce forest soil is blackened.

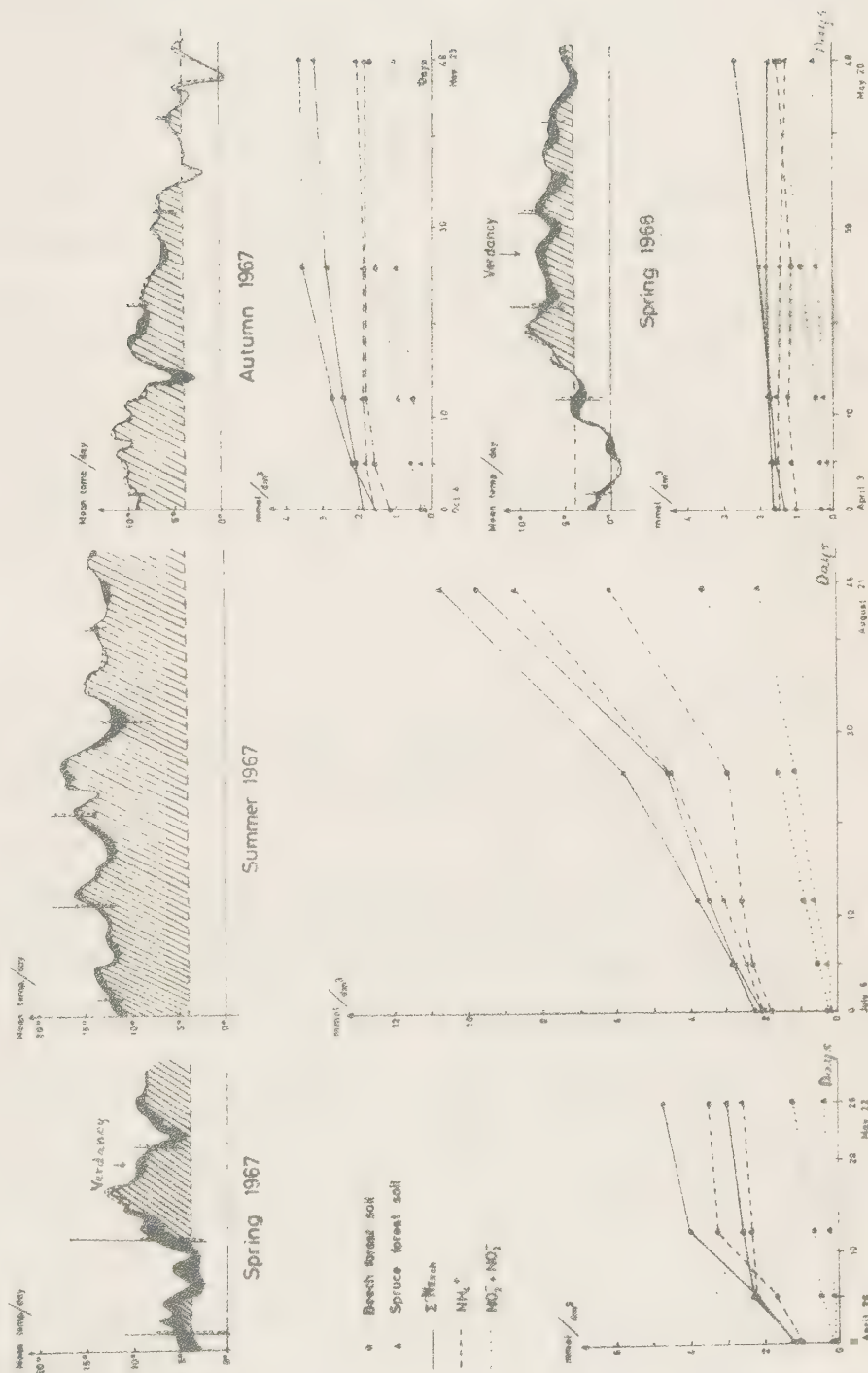


Table 5. Amounts of C and N in the soil surface litter of the beech and spruce forest in Kongalund (II). Figures in parentheses are 95 % confidence limits (n=10). Ton/ha=10³ kg/ha. Sampling day July 7, 1967. Drying temperature 85°C.

Kind of litter	Litter ton/ha	Carbon ton/ha	Nitrogen ton/ha	C/N
Beech forest soil				
Leaf litter	4.1	2.11	0.078	27
Branch litter	1.1	0.56	0.008	72
Σ	5.2(±1.2)	2.67(±0.63)	0.086(±0.20)	31
Spruce forest soil				
Needle litter	12.7	6.35	0.208	31
Branch litter	5.8	2.72	0.037	73
Σ	18.5(±2.6)	9.1(±1.3)	0.245(±0.035)	37

Table 6 Water content, loss on ignition and tot.-N of the mobilization experiments, representing different seasons of the year and the upper 3 cm of the soil. For 1967 an estimation is made of the mobilized nitrogen during the vegetation period of the same horizon.

Season	Water content % fresh weight		Loss on ign. % dry weight		Tot.-N kg/ha		Mobilized N kg/ha	
	Beech	Spruce	Beech	Spruce	Beech	Spruce	Beech	Spruce
Spring 1967 (30 days)	45.6	61.3	20.8	62.0	800	780	19.3	9.7
Summer 1967 (120 days)	41.3	57.6	20.3	62.7	850	710	72.0	85.5
Autumn 1967 (30 days)	48.1	62.5	24.6	69.4	370	340	8.7	4.4
Σ	-	-	-	-	-	-	100.0	99.6
Spring 1968	46.4	62.3	19.4	54.3	820	680	-	-

As a steady state ought to exist at least in the beech forest soil, the amount of nitrogen in the litterfall ought to equal the nitrogen released through mineralization. This is obviously not the case as the values of mineralized nitrogen are much higher. Moreover nitrogen mineralization takes place not only in the upper 3 cm but in the whole soil profile.

Several objections can naturally be raised against the mobilization experiments. The most important is perhaps that the natural soil structure is disturbed during sampling, and the homogeneizing of the soil may favour the distribution of the microbes and then favours also the nitrogen mineralization. Moreover the release of nitrogen from killed small roots may be high. Olsen (1932) showed that beech leaves could bind high amounts of ammonia, but this happened only at pH-values above 5.0. As the pH of the soil samples of Kongalund were 4.1 and 3.6 in the beech and spruce forest respectively, this binding ought not to be of importance.

10. Summary and discussion

The main pedological changes occurring when spruce is planted on former beech forest soils in Scania are summarized in the following paragraphs:

- a. In the soil profile it is possible to see a change from mull to mor. Moreover podsolizing effects are observable, i.e. indication of a leaching horizon just below the mor, and a precipitation horizon further down. Obviously leaching processes are accelerated in the soils of planted and dense spruce forests. These changes are less observable when the mull horizon of the former beech forest soil is thick.
- b. Owing to the accumulation of organic matter in the soil surface of the spruce forests, some physical properties are changed (specific gravity, bulk density, porosity, water holding capacity at pF 2.0).
- c. The amount of available water is low in the spruce forest soil throughout the year, and the water-transport to the underground-water is probably very low in the spruce forest.
- d. Considering the soil chemistry, the concentration of some

exchangeable nutrients decreased (K, Ca) while some others increased (PO_4 , Fe) in the upper horizon of the spruce forest soils. pH decreased at least to a depth of 50 cm in the spruce forest soils.

- e. The soil organic matter showed a higher C/N-ratio in the spruce forest soils.
- f. The litter layer has usually increased in weight in the spruce forests compared with the beech forests.
- g. In the mineralization of nitrogen a lower percentage of ammonia is transferred to nitrate in the spruce forest soils.

Similarly, an accumulation of organic matter, a decrease in pH, of exchangeable K, Ca, Mg and tot.-N of the upper humus horizon of the spruce forest soils in Germany, is reported by Genssler (1959). Lundblad (1924) showed the degeneration of brown earth in terms of extractable silica, iron and aluminium, and found an increase of these elements in spruce forest soils planted on former beech forest soils. Noirfalise (1964) gives a good survey of the pedological and biological deteriorations that are found in the deciduous zone of temperate Europe when spruce replaces beech, and my results are in agreement with them. Mina (1967) showed that the very acid stem flow of the spruce trees had a permanent and possibly an irreversible, negative and podzolizing effect on the soil.

The question remains as to whether the observed changes in a podsolizing direction will proceed during following generations of spruce. This does not seem to be the case of the mountain areas investigated by Genssler (1959) or of the second generation of spruce in Denmark (Holmsgaard et al. 1961). However, the following facts should be borne in mind:

- a. Leaching processes always occur from the soil surface and downwards, and are accelerated by low pH-values.
- b. There is only a slight difference in the pH (water extract) from the soil surface and downwards of the beech forests, but almost half a degree lower in the planted scanian spruce forest soils.
- c. The leaching medium is rainwater. This is already more than one pH-unit lower in the spruce forest compared with the beech forest, when reaching the litter of the soil surface (Nihlgård 1970 b).

d. In the beech forest soil the mull horizon, when appearing, ought to have a high biological activity and a neutralizing effect on acid substances. This effect certainly has decreased in the degraded and podsolized humus horizon below the mor in the spruce forest soils.

These facts would logically speak for a continuous influence by acid substances from the surface and downwards, especially in the spruce forest soils, thus increasing the podsolizing effects.

The podsolizing process is of course modified by the mineral composition, the structure and texture of the soil and by the influence of ground water. The soils that ought to be most seriously damaged are those with a biologically weak and thin mull horizon when appearing under beech. In connection with a poor mineral composition, that is with a low content of basic elements and plant nutrients, and without influence from ground water, the podsolization must be accelerated where spruce is growing in dense plantations.

11. Acknowledgements

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VI. BIOMASS, PRODUCTION AND CHEMICAL ELEMENTS

Plant biomass, primary production and distribution of elements of a beech and a planted spruce forest ecosystem in south Sweden

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Abstract

Plant biomass, primary production and distribution of chemical elements within a beech forest ecosystem and a 55-year old planted spruce forest ecosystem at Kongalund, South Sweden, are described and discussed. The stands are situated side by side on soil with the same mineral composition and with the spruce forest growing on former beech forest area. The figures for biomass and productivity were about equal in the two stands. 60% of the production of the beech forest was concentrated on the branches, while in the spruce forest about 60% instead was concentrated on the stem production. The distribution of water in the spruce forest was relatively more concentrated to the live plant material than to the soil, compared with the beech forest. Certain differences existed concerning the chemical distribution of elements in different fractions of the ecosystems. Some elements had decreased in the spruce forest compared with the beech forest, e.g. Ca, Mg and N, while e.g. S and Mn had increased. Correlated changes were found in the plant material and in the exchangeable fraction of the soil. Some functional aspects are given on the organic matter and on the mineral cycling. It is shown that the circulation rate, the change in element concentration with age, and the addition of elements from aerosols is varying for different elements.

1. Introduction

In previous papers the microclimate, the precipitation, the soil physical and chemical status of a special investigated area in Kongalund, southern Sweden, are described (Nihlgård 1969, Nihlgård 1970 a, b). The area is composed of an uneven-aged beech forest and an planted evenaged spruce forest situated side by side on soil with the same textural composition.

In this paper the plant biomass, the net primary production and the litterfall of the two ecosystems are described. Further the ecosystem distribution of the organic matter, of the most important chemical elements and of water during summer time is described. Some functional aspects of the nutrient balance will also be given.

2. Description of the site.

Kongalund, situated in the northwestern part of Scania, southern Sweden ($55^{\circ}59'N, 13^{\circ}10'E$), is mainly an old beech forest area. It has belonged to the estate of Knutstorp during the last two hundred years (Håkansson 1948). Originally it was preserved as a hunting park but it has also been properly managed from an economic forestry point of view, and may be regarded as an average productive beech forest in Scania. In several parts of Kongalund spruce plantations occur, planted on the former beech forest soil.

The bedrock of Cambrian shales and sandstones is overlaid by a thick layer of glaci-fluvial moraine with an even distribution of grain sizes. The soil type is an acid brown forest soil. The yearly precipitation is about 800 mm, the average yearly temperature $6-7^{\circ}C$. For further details of climate and soil see Nihlgård op. cit.

On plain ground and 60 m apart, two 1000 m² large areas were investigated, one in the beech and one in the spruce forest.

Average values of some stand properties are given in the following table, referring to 1968:

	Age (years)	Density (trees/ha)	Average diam.(cm)	Average height(m)	Est.crown cover(%)	Basal area (m ² /ha)
Beech forest (range)	90 (45-130)	240 -	39 (12.3-64.0)	25 (11.0-29.0)	80-90 -	31.4 -
Spruce forest (range)	55 -	880 -	28 (15.3-37.6)	25 (18.0-28.0)	80-90 -	55.6 -

No tree-cutting has taken place since 1960-62 and the distribution of diameterclasses and heights is normal (Fig. 1). The beech forest has an almost closed field layer dominated by *Stellaria nemorum*, *Lamium galeobdolon* and *Oxalis acetosella* (Fig. 2). Moreover there is *Anemone nemorosa* in the vernal aspect. The spruce forest is still too dense to allow the growth of a field layer and has only scattered individuals of *Oxalis acetosella*, *Dryopteris spinulosa*, *Rubus idaeus* and juvenile *Sorbus aucuparia* (Fig. 3).

3. Terminology and methods

The terminology and the principal methods used at the biomass and production measurements follow Andersson (1970).

To estimate the production and the biomass of a tree-layer one can adopt allometric regressions of the type $y = ax^b$ or $\log Y = b \cdot \log x + A$, where y is a destructive variable, e.g. weight of stems or branches, x is a nondestructive parameter e.g. the square of the diameter at breast height times height (D^2H), b is the regression coefficient and A the regression constant (cf. Whittaker & Woodwell 1969, Newbould 1967). At the actual measurements D^2H gave better correlations and more adequate inclination of the regression lines than did e.g. DH or girth.

As pointed out by Andersson (1970 p. 21) there are four basic steps at the estimation of the biomass and the production of a tree-layer: a) Stand analyses by non-destructive measurements, b) Destructive measurements of sample trees, c) Application of the stand to the regressions of the sample trees, and d) Additional observations regarding e.g. the litterfall throughout several years.

a) The stand analyses were performed inside the 1000 m² investigation areas. The diameter at breast height (D) was crosscalipered in mm with a steel calliper. The height and the lower

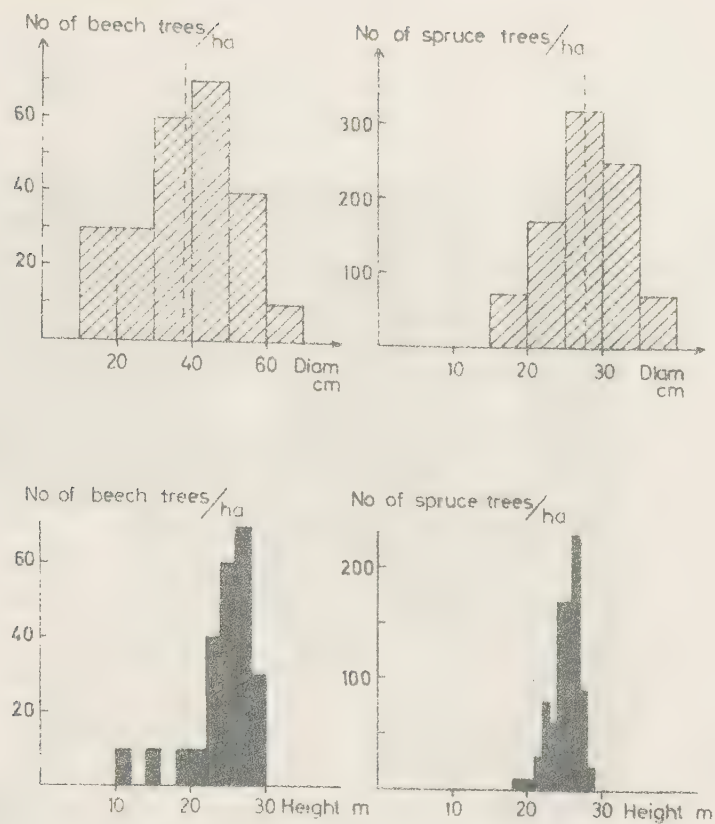


Fig.1 . The distribution on diameter and height in the beech forest (to the left) and the spruce forest (to the right).



Fig.2 . The investigated beech forest area with littertraps and raingauges. June 1968.



Fig.3 . The investigated spruce forest with some littertraps and raingauges. June 1968.

limit of the crown was measured with an accuracy of ± 0.5 m with a Blume-Leiss instrument.

b) 1. Destructive biomass measurements. Eight trees of each the beech and the spruce forest were subjectively selected and cut in the neighbourhood of the investigation areas. The sample trees represented the range of different diameters and heights of each stand. One medium large tree of each stand was felled in the middle of July 1967, mainly for nutrient analyses. The other were felled during September 1968 or 1969.

At the cutting the limit to the stump, i.e. the limit to the below ground biomass, for practical reasons was set at 15 cm above the soil surface. The stem was divided into 5-10 logs, which were weighed and cross-calipered at both ends (D_1 and D_2). The biggest logs were usually too heavy for the used balance (max. 105 kg) and they were either divided into small pieces or the weight was calculated via the volume, using the volume/weight ratio of the above situated log. The volume was calculated according to the formula $V = \pi \cdot \frac{D_1^2 + D_2^2}{8} \cdot h$, where D_1 and D_2 are the end diameters and h the length of the log. This calculation proved to be very good, with errors of about 2%.

Sample discs, 5 - 10 cm tall, were cut at the base of each log and taken home for annual ring analysis and for determination of dry weight (85°C) of both bark, which was peeled off, and of wood. The diameter below bark was also cross-calipered and the bark volume was estimated as the difference between the volume over and under bark (formula as above).

From the annual ring analysis the total age of the disc was obtained. Further the increment, in mm, of the last five years was measured in four radii and the volume five years ago was calculated. The beech branches were weighed separately and discs from the bases were taken for determination of diameter and age. On the whole crown of the two smallest beech trees and on 24 sample branches, representing different diameters and originating from different parts of the crowns of the trees a more careful analysis was performed on the number and weight of current twigs including leaves and fruits. An allometric logarithmic regression equation with total branch weight as the independent variable (cf. Table 1) was used to estimate the current twigs of each branch, which were summed for each sample tree. Subsamples of the current twigs gave the further division into leaves (blades and petioles) and twigs.

The branches from each spruce tree were weighed in a lump, though attached dead was separated. The lower limit of the spruce crown was measured and the age at this height was determined from a sample disc. 5 - 10 spruce branches from each tree, representing the crown, were analysed on current twigs and were taken home for estimating the ratio between needles and branch wood and bark. The needles easily fell off during drying.

The below ground biomass was determined on three trees of different diameters of each stand. On the medium tree the roots were carefully dug up within a radius of 2-3 m and the soil was sieved (6 mm sieve) to get as complete biomass as possible. A division was made into stump + big roots (>5 cm in diam.), medium roots (diam. 5-0.5 cm) and small roots (< 5mm diam.). The latter fraction appeared to make up only a few percent. The other stumps were blustered up with dynamite and a small correction for small roots was then introduced. However, the very fine small roots were impossible to measure, and in summing up the total root weight an addition of 0.5 and 0.8 ton/ha was made in the beech and the spruce forests respectively.

b) 2. Destructive production measurements and calculations

Production of the stem wood was founded on the annual ring analyses of the discs (cf. above), and calculated on each log. The annual volume increment (ΔV_s) was supposed to be linear during the latest five years: $\Delta V_s = \frac{V_s - V_{s-5}}{5}$, where V_s and V_{s-5} are the stem log volume today and five years ago. ΔV_s was transformed to weight (ΔW_s) using the volume/weight ratio of each log. The annual weight increment of the trees was then set up in a logarithmic regression on D^2H .

Production rate of the stem bark ($\frac{\Delta W_b}{W_b}$) was supposed to equal the production rate of the stem wood ($\frac{\Delta W_s}{W_s}$), and thus the stem bark growth was: $\Delta W_b = W_b \cdot \frac{\Delta W_s}{W_s}$;

(Whittaker & Woodwell 1968 p. 5).

Production of branch wood and bark (ΔW_B) was estimated by the relation $\Delta W_B = b \cdot \frac{W_B}{x}$, where x is the age and W_B is the dry weight of the branches excluding current twigs with leaves.

b is a regression constant obtained from the logarithmic regression of branch dry weight on age: $\log W_B = b \cdot \log x + A$

(Whittaker and Woodwell op.cit.). The growth of the branches was summed for each sample tree and the obtained values were used in a new regression on D^2H . This estimation was possible

only of the beech branches where the age was revealed by the annual rings. The spruce branches showed annual rings of only 6 - 8 years, though they were much older. The annual growth of the spruce branches were therefore roughly estimated (current twigs and needles excluded) by dividing the weight of the whole tree crown by the age of the stem at the lower limit of the crown. This limit was defined as the point where live branches occurred around the stem. The age at this limit showed to be 22-26 years. This probably is an under-estimation of the branch-production, as at least some twigs of the lowest situated branches already are lost, but it was not possible to do an adequate correction. The production of current twigs with leaves or needles was estimated for each sample tree (cf. biomass measurements), and these values were set up in a logarithmic regression on D^2H .

The below-ground production (ΔW_R) was estimated principally in the same way as the stem bark production, assuming that the production rate below ground was the same as above ground:

$\Delta W_R = W_R \cdot \frac{\Delta W}{W}$, where W_R is the root biomass, ΔW the above ground production and W the above-ground biomass.

c. Application to the stand. D^2H -values of the trees of the investigated stands were applied to the different regressions of the sample trees (cf. Table 2). The regression and application to the stand calculations were made on a computer, programmed to give also the total error involved in the estimation procedure (cf. Andersson 1970, p. 25). The variance was calculated for each tree at the application step, and on the summed variance 95% confidence limits were calculated and are given in the table (Table 3).

d. Additional observations. To get complete tree production figures an addition must be made for annual produced matter, which has been rejected from the trees as litterfall before felling of the sample trees. This is a small fraction comprising early rejected leaves, flowers and fruits.

The litterfall was measured in ten litter traps, systematically distributed over each investigation area (Figs. 2 and 3). A litter trap was made of a terylene mesh bag suspended from an aluminium hoop. The trapping circle surface was 0.25 m^2 and situated 1 m above ground. During 1967 the traps were emptied once a month and the material was chemically analysed. During 1968 and 1969 the traps were emptied about every second month. Coarse litter, i.e. branches longer than 0.5 m, was sampled

once a year (1968 and 1969) in the whole investigation area of the beech forest and in a 10 x 10 m area of the spruce forest.

To get total net primary production also the field layer must be regarded. The above ground production of this was roughly estimated as the maximum biomass of the vernal aspect (mainly *Anemone nemorosa*) plus the maximum of the summer aspect (mainly *Stellaria nemorum* ssp. *glochidosperma*, *Oxalis acetosella*, *Lamium galeobdolon*). The biomass of the above-ground field layer was estimated from ten samples, each 0.25 m², of each stand. The below-ground biomass was estimated from six 10 litre samples of the soil surface 0-10 cm, and the annual production of this was roughly set as one third of the biomass. Leaf area was on beech leaves determined as the upper area of the leaves. Spruce needles were measured in width and length and the leaf area was approximated as the half of the area of a regular prism.

e. Chemical analyses. Chemical analysis was performed on the litterfall at all sampling occasions during 1967. The soil surface litter, as ten 0.25 m² samples from each stand, was taken and analysed during July 1967, and so was one sample tree of each stand. For methods see also earlier described precipitation analyses and soil water investigations (Nihlgård 1970 a) and soil chemical analyses (Nihlgård 1970 b). The latter were also performed during July 1967.

The chemical plant analysis comprised determinations of Na, K, Ca, Mg, Fe, Mn, S, P, Si, N and C. The material was dried at 85°C and a digestion according to Johnson & Ulrich (1960) was performed. 0.5000 or 1.000 g was digested by HNO₃ + HClO₄, at a temperature below 210°C. It was boiled to almost but not complete dryness. To the residue was added water or if necessary 0.1 M HCl. Na, K, Ca, Mg, Fe and Mn were determined on a Perkin-Elmer Atomic Absorption Spectrophotometer, Ca and Mg in a 1% La-solution (Pawluk 1967). S was determined turbidimetrically as SO₄ (Blanchard, Rehm & Caldwell 1965), P according to the colorimetric PO₄-vanadate method (Jackson 1958). Si was determined gravimetrically as the residue (SiO₂) after the above mentioned digestion. N was determined with a semi-micro Kjeldahl method, - digestion in H₂SO₄ and H₂O₂, catalyzors K₂SO₄, CuSO₄ and HgSO₄. C was determined by a wet combustion method (Jansson & Waldmaa 1961). The errors of these laboratory analyses, as estimated from double analyses, were in the order of 2 - 7% (cf. Nihlgård 1970 a, b).

4. Plant biomass and primary production

Table 1 and Table 2 give the main results of the analysis of the sample trees. It is also possible to reconstruct the regression lines that could be raised upon the sample tree data. For the application step the data in Table 2 were necessary and to get deviation figures also the sum of the square deviations was used. It was striking to find very high correlation coefficients of almost every regression. Cf. Fig. 4.

It is notable (Table 1) that the branch biomass fraction of the beech trees almost equaled half the stem biomass, and that the branch production was the main production fraction of the beech trees. Thus almost 60% of the total annual production was concentrated on the branches, including current twigs with leaves. For the spruce trees corresponding figure was less than 30%, and instead almost 60% was concentrated on the stem production.

Table 3
The above ground total biomass was slightly higher in the beech forest and so was the total production. This was mainly owing to the high biomass and production figures of the branches in the beech forest. On the other hand the stem biomass fraction was 16 % higher (= 41 ton/ha) in the spruce forest, and the stem production was 49 % (= 4.6 ton/ha) higher in the spruce compared with the beech forest. The stem bark biomass and production was considerably higher and the current twig biomass and production somewhat lower in the spruce forest.

In estimating the total production of the tree layer an addition was made for early litterfall with 0.2 and 0.1 ton/ha in the beech and the spruce forests respectively (Table 3). This amount was obtained as a small part of "other material" (cf. Table 6), released during April-August. It was difficult to know how much of the bud scales and flowers that ought to be considered as new produced material and not included in the buds of current twigs, and 0.2 and 0.1 ton/ha are approximations.

Table 1. Mean relations and percentage distribution of different fractions of the sample trees.
Weight figures at 85°C.

		Beech	Spruce
A. Mean relations of sample trees			
Height (m)		20.4	24.6
Diameter at breast height (cm)		29.6	27.7
Age (years)		78	55
Biomass above-ground (kg)		932	358
" below- " (kg), interpolated		137	65
Ratio shoot:root		6.8	5.5
Net production above-ground (kg)		39.6	16.2
" " below- " (kg), approx.		5.8	2.9
Stem volume (dm ³)		1068	867
Branch " (dm ³)		525	79
Stem volume-increment (dm ³ /year)		22.2	28.2
Branch " " (")		27.9	3.1
Weight: volume ratio (kg/dm ³)		0.58	0.38
B. Percentage distribution of biomass		≤ 100 %	≤ 100 %
Stem wood (%)		55.9	65.8
Stem bark (%)		2.5	5.8
Branch wood and bark (%)		27.8	6.8
Old needles		-	5.0
Current twigs with leaves (needles) (%)		1.0	1.2
Stump and big roots (>50mm) (%)		9.6	14.0
Medium roots (50-5mm) (%)		2.1	1.1
Small roots (<5mm)		1.1	0.3
C. Percentage distribution of production		≤ 100 %	≤ 100 %
Stem wood (%)		27.2	52.8
Stem bark (%)		1.2	4.7
Branch wood and bark (%)		36.0	5.7
Current twigs with leaves (needles) (%)		22.8	21.4
Stump and roots (%), approx.		12.8	15.4
D. Current twig distribution into			
Twig and bud (%)		18.2	25
Blades (%)		78.2	75
Petioles (%)		3.6	-
E. Leaf area (cm ²)		20.8	~ 0.25
F. Leaf weight (g)		0.22	0.0045
G. Leaf area index (ha/ha)		2.9 (3.4)	11.5

Table 2. $\log_{10}$ regression-data on dry weights (85°C) of the beech and the spruce forests. $\bar{X}$ and $\bar{Y}$ are mean values of the independent and dependent variable respectively.

B = Beech forest, S = Spruce forest.

Regression	$\log_{10} Y = \log_{10} X \cdot b + A$	$\bar{X}$	$\bar{Y}$	Intercept (A)	Regr. coeff. (b)	Corr. coeff. (r)	Mean square (MSQ)
Biomass regressions							
D^2H (cm ² ·m)(x) on above-ground total biomass (kg)	B S	4.0515 4.2420	2.4998 2.4886	- 1.7194 - 1.2908	1.0414 0.8910	0.999 0.994	0.0017 0.0010
D^2H on root biomass (kg)	B S	4.4319 4.1929	2.0494 1.7234	- 2.8434 - 2.0274	1.1040 0.8946	1.000 0.997	0.0004 0.0023
D^2H on stem wood biomass (kg)	B S	4.0515 4.2420	2.3537 2.3844	- 1.6219 - 1.2187	0.9813 0.8494	0.998 0.989	0.0033 0.0017
D^2H on stem bark biomass (kg)	B S	4.0515 4.2420	1.0709 1.3427	- 2.4279 - 1.8073	0.8636 0.7426	0.992 0.998	0.0082 0.0003
D^2H on branch biomass (kg)	B S	4.0515 4.2420	1.8454 1.6210	- 3.2114 - 3.6280	1.2481 1.2374	0.994 0.998	0.0133 0.0008
Branch age on branch wood with bark (kg)	B	1.4626	0.9082	-	2.5090	0.8713	0.0121
Beech branches on current twigs with leaves (kg)	B	0.7475	-0.4079	- 0.9006	0.6592	0.913	0.0579
Production regressions							
D^2H on above-ground total produktion (kg)	B S	4.0515 4.2420	1.2079 1.1162	- 2.6495 - 3.3892	0.9521 1.0621	0.999 0.997	0.0006 0.0007
D^2H on stem wood produktion (kg)	B S	4.0515 4.2420	0.7508 0.9226	- 2.8824 - 3.3006	0.8968 0.9956	0.992 0.992	0.0092 0.0016
D^2H on stem bark produktion (kg)	B S	4.0515 4.2420	-0.5314 -0.1184	- 3.6776 - 3.8684	0.7766 0.8840	0.995 0.992	0.0039 0.0014
D^2H on branch produktion (kg)	B S	4.0515 4.2420	0.7073 -0.0805	- 3.8939 - 5.2875	1.1357 1.2275	0.994 0.992	0.0099 0.0025
D^2H on current twigs with leaves	B S	4.0515 4.2420	0.6978 0.4828	- 2.9147 - 4.7360	0.8916 1.2303	0.994 0.991	0.0066 0.0028
D^2H on volume produktion (dm ³)	B S	4.0515 4.2420	1.3308 1.3647	- 2.4761 - 3.0358	0.9396 1.0374	0.997 0.990	0.0038 0.0023

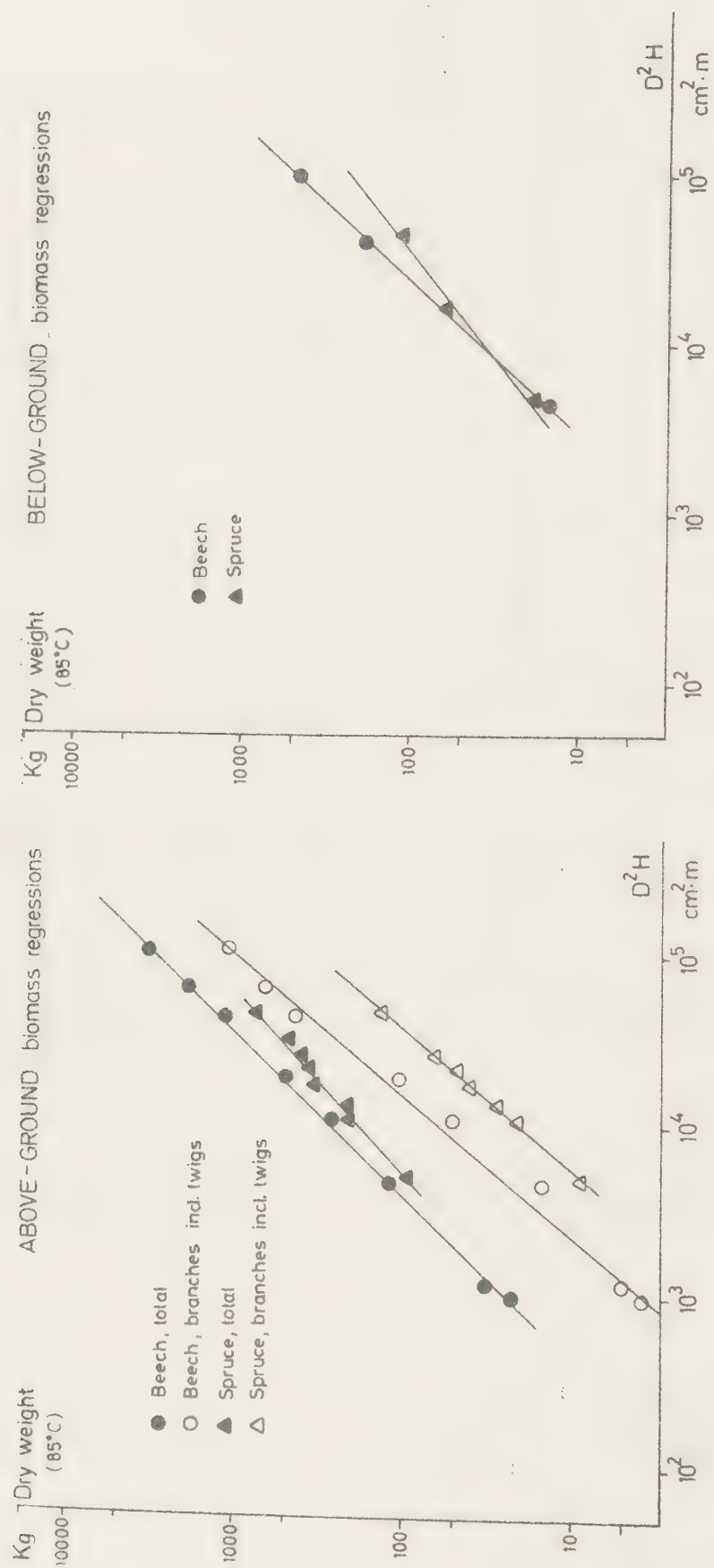


Fig.4 . Diagrams showing some above- and below-ground biomass regressions of the beech and the spruce forests.

Table 3. Biomass and yearly production figures of the beech and the spruce forests. 95 % conf. limits obtained at the application step are given.

	Beech forest	Spruce forest
BIOMASS, ton/ha		
Stem wood	212 ± 14	240 ± 10
Stem bark	9 ± 1	22 ± 0.3
Branches (total)	103 ± 15	46 ± 1.3
Field layer (July 1967)	0.2 ± 0.05	< 0.01
Total above ground	324 ± 15	308 ± 10
Tree roots (from regression)	49 ± 2	58 ± 4
Herb roots (July 1967)	1.5 ± 0.3	< 0.01
Additional fine roots (approx.)	0.5 -	0.8 -
Total below ground	51 (± 2)	59 (± 4)
PRODUCTION, ton/ha		
Stem wood	4.6 ± 0.5	8.6 ± 0.3
Stem bark	0.2 ± 0.02	0.8 ± 0.03
Branches (wood and bark)	6.2 ± 0.7	0.9 ± 0.04
Current twigs with leaves	3.9 ± 0.4	3.3 ± 0.2
Additional early litterfall	0.2 ± 0.02	0.1 ± 0.02
Field layer	0.3 ± 0.08	< 0.01
Total above ground	15.4 ± 0.4	13.7 ± 0.3
Root production (approx.)	2.4 -	2.6 -
TOTAL, ton/ha		
Total biomass	375 (± 17)	367 (± 14)
Total production	17.8 (± 0.5)	16.3 (± 0.5)
VOLUMETRIC VALUES (m ³ /ha) above ground		
Total volume on bark (stem and branches)	553 ± 20	802 ± 25
Volume production (stem and branches)	18.7 ± 1.4	26.6 ± 1.1

The volumetric production figures were much higher in the spruce forest due to a low volume-weight of the wood. Considering only stem volume production the figures were about $8 \text{ m}^3/\text{ha}$ and $23 \text{ m}^3/\text{ha}$ in the beech and the spruce forests respectively. In the economic utilization of the beech timber also branches down to a diameter of seven cm are used. This part approximately makes up another $5 \text{ m}^3/\text{ha}$ in the beech forest.

The volume production figures may be regarded as high, but it must be remembered that they are mean values of only the latest five years and that the stands consist mainly of big trees growing rapidly. Carbonnier (1954) showed how the current annual increment was steadily increasing between 30 to 70 years of age in planted spruce forests in the "Tönnersjö-heden", South Sweden. The Kongalund spruce forest showed a volume production that was in agreement with self-thinned plots from "Tönnersjö-heden". Judging from the tables of Mar:Möller (1933) from Denmark, the spruce forest of Kongalund belongs to site quality I and the beech forest to site quality III (-II).

The total leaf weight of the beech forest was about $3,1 \text{ ton/ha}$, and the total needle weight of the spruce forest was about 18 ton/ha . Considering these amounts as the assimilating organic material, the production capacity/weight of leaves is much higher in the beech forest (cf. Malmer 1969). The total photosynthesizing leaf area of the beech forest was approximately 2.9 ha/ha (Table 1), which is about four times less than in the spruce forest. However, the estimation of leaves from the regression calculations may be too low. The litterfall of beech leaves and spruce needles showed higher values than the amount of leaves, included in current twigs, estimated from the regressions. Using the litter values of the beech forest leaves (3.57 ton/ha) gave a leaf area index of 3.4 instead of 2.9 ha/ha .

What concerns the production of spruce forest needles their relation to the litterfall is discussed below. The main objection that can be raised on the assimilating organs of the spruce forest, is that it is unknown how many of the old needles that really photosynthesize.

The below ground biomass (stump + roots) made up 13 % and 16 % of the total biomass of the beech and the spruce forests respectively. It should be remembered that a stump of 15 cm height

is included. A remarkable difference in the morphological appearance of the roots was noted (Fig. 5). Of both the beech and the spruce trees the greatest part of the below ground biomass was situated in the upper 50 cm of the soil. Below the stump of the beech tree the soil was totally interwoven by anastomosing, medium large (diameter 5 - 50 mm) and small (< 5 mm) roots. From the stump of the spruce tree some large roots went in a horizontal direction and from these a few big downward directed roots went to a depth of 50-110 cm, suddenly ending in bunches of small roots. The main part of small roots were otherwise found in the soil surface (0 - 10 cm) of both the beech and the spruce trees.

5. Organic matter, nutrients and water

The organic matter of a forest can be divided into tree main fractions: (1) The living fraction above and below the soil surface (2) The surface litter (3) The soil organic matter (Table 4). The main difference between the Kongalund stands existed in fraction (2), which was about 4 times greater in the spruce forest stand, but taken together the organic matter in July 1967 was only slightly higher in the spruce forest.

The water distribution of the ecosystems during July 1967 showed interesting differences (Table 4). The soil water content down to a depth of 60 cm was 520 ton/ha lower of the spruce forest soil (cf. Nihlgård 1970 a and b). On the other hand the water content of the plant biomass was 80 % or 240 ton/ha (= 24 mm rain) higher in the spruce forest. Thus the dry soil conditions of the spruce forest partly is explained as a matter of redistribution of water within the ecosystem.

Taken together the amount of Na, K, Ca, Mg and Fe was 11 % lower in the organic matter of the spruce forest, in spite of a slightly higher amount of organic matter compared with the beech forest. The exchangeable amounts of the same elements in the soil were also lower in the spruce forest. These amounts, which are regarded as those available to plants, constitute less than one thousandth of the total amount of corresponding minerals in the soil (see Nihlgård 1970 b), but they are taken into consideration here as the active, functional part of the minerals. It was notable to find a relation between the mine-

Table 4. Distribution of organic matter, water and chemical elements within the beech and spruce forest ecosystems. July 1967.

FRACTION	Organic matter ton/ha		Water ton/ha		Nitrogen ton/ha		Mineral elements, Ca, Mg, Fe		Si, S, P, Mn	
	Beech	Spruce	Beech	Spruce	Beech	Spruce	Beech	Spruce	Beech	Spruce
Living above ground	324	308	231	429	1.06	0.77	1.22	1.02	0.28	0.37
" below "	51	59	53	81	0.15	0.09	0.16	0.14	0.05	0.03
Surface litter	5	13	5	13	0.05	0.25	0.05	0.11	0.03	0.09
Σ	380	386	290	529	1.30	1.11	1.43	1.27	0.36	0.49
(Spruce-Beech) x $\frac{100}{\text{Beech}}$, %	0.0	+1.6	0.0	+82.5	0.0	-14.6	0.0	-11.2	0.0	+36.1
Soil (0 - 65 cm)	207	207	1920	1400	7.80	6.90	0.32	0.30	0.51 ¹⁾	0.92 ¹⁾
							exch.	exch.	exch.	exch.
Total Σ	587	593	2210	1929	9.10	8.01	1.75	1.57	0.87	1.41
(Spruce-Beech) x $\frac{100}{\text{Beech}}$, %	0.0	+1.0	0.0	-12.7	0.0	-12.9	0.0	-10.3	0.0	+62.0

1) Si is not included in this figure.

ral elements of the biomass - surface litter fraction and those of the exchangeable fraction. E.g. Ca and Mg both had decreased in the organic matter of the spruce forest, and so had the exchangeable amount in the soil, compared with the beech forest, Mn, on the other hand, had increased in both fractions (Table 5).

Nitrogen showed obvious trends with low values in both the above and below ground organic matter of the spruce forest.

Si + S + P + Mn (Table 4) all had an opposite trend, with an increase in the above-ground organic matter and in the exchangeable amount of the soil in the spruce forest. Si, P and Fe showed a different distribution above and below the ground within the two ecosystems. Thus the very hard beech roots contained more of these elements than the soft spruce roots, but above ground the organic matter of the spruce forest contained more than the beech forest (Table 5).

The above mentioned differences between the beech and the spruce trees in the elemental composition, were visible in most of the fractions of the plant biomass (Table 5), With the exception of K and P, the current twig fraction of the spruce forest showed low concentrations of most elements compared with the beech forest. Instead the old branch needles had increased their content of especially Si, Na, Ca and Mn. K, P, N and Mg had decreased their concentration with increased age of the needles (cf. Ulrich, Reemtsma & Kalan 1968). The bark of both the beech and the spruce trees was very concentrated in different elements.

A comparison of the chemical elements in Kongalund with those surveyed by Ovington (1962) shows that in the organic matter, the Na, K, N- figures of Kongalund were relatively high, Ca and Mg figures relatively low, and the P-figures were approximately in the same range. The exchangeable amounts of the soil were usually lower in Kongalund, which probably has a methodological explanation.

Table 5 A. Distribution of chemical elements in living plant fractions of the beech forest. July 1967.

FRACTION and fraction weight	C		N		Si	Na	K	Ca	Mg	Fe	Mn	S	P
	ton/ha		ton/ha							kg/ha			
Stem wood,	212	ton/ha	102	0.21	4.7	16.1	182	111	51.5	3.6	34.9	23.8	17.7
Stem bark,	9.0	"	4.5	0.08	2.9	1.0	19	90	5.5	1.8	9.4	4.9	4.7
Branch wood and bark	99	"	50	0.66	12.2	13.4	228	381	40.9	9.4	59.8	34.9	55.2
Current twigs,	4.0	"	2.0	0.10	1.3	1.6	23	20	6.8	0.6	6.6	4.4	6.2
Field layer,	0.2	"	0.1	0.01	0.02	0.14	8	0.9	0.1	0.04	0.5	0.2	0.7
Total above ground	384		159	1.06	21.1	32.2	460	500	104.3	15.4	111.2	66.2	84.5
Stump and big roots	37	"	19	0.07	4.1	2.7	39	21	7.2	5.2	5.7	7.7	5.7
Medium roots	8.0	"	4.1	0.04	2.2	2.3	21	12	2.7	2.0	2.9	3.3	5.2
Small roots	6.0	"	3.0	0.04	5.2	1.5	19	9	3.6	6.9	2.1	3.5	4.7
Total below ground	51	"	26	0.15	11.5	6.5	79	42	13.5	11.5	14.6	14.5	15.6
Σ	375 ton/ha		185	1.21	32.6	38.7	539	645	118	26.9	126	82.7	100
			C/N=153										

Table 5 B. Distribution of chemical elements in living plant fractions of the spruce forest. July 1967.

FRACTION and fraction weight	C		N		Si	Na	K	Ca	Mg	Fe	Mn	S	P
	ton/ha		ton/ha		kg/ha								
Stem wood,	240	ton/ha	118	0.17	7.4	20.4	103	115	17.5	2.7	54.0	57.6	14.9
Stem bark,	22	"	11	0.10	3.1	3.5	69	168	21.4	3.1	29.0	11.3	13.6
Branch wood and bark,	25	"	13	0.23	3.8	8.4	112	86	18.2	7.0	17.3	20.0	30.2
Branch needles	18	"	9.0	0.22	12.3	4.9	122	84	9.6	2.0	40.5	20.7	21.8
Current twigs,	3.3	"	1.7	0.05	0.1	0.3	31	6	2.5	0.2	2.1	2.6	6.5
Field layer,	0.01	"	<0.01	<0.001	<0.01	<0.01	0.02	0.1	<0.01	<0.01	0.02	0.01	0.02
Total above ground,	308	"	153	0.77	25.7	37.5	437	459	69.2	15.0	142.9	112.2	37.0
Stump and big roots,	52	"	26	0.05	1.3	1.8	51	23	7.0	3.5	10.0	10.0	2.4
Medium roots,	4.5	"	2.3	0.02	0.1	0.5	8	14	1.9	0.7	2.7	2.6	1.7
Small roots,	2.0	"	1.0	0.02	0.4	1.4	6	8	1.6	1.2	2.3	1.9	1.6
Total below ground	59	"	29	0.09	1.8	3.7	65	45	10.5	5.4	15.0	14.5	5.7
Σ	367 ton/ha		182	0.36	28.5	41.2	502	504	79.7	20.4	158	127	92.7
			C/N=212										

6. Functional aspects

To understand the function of an ecosystem it is fruitful to set up even a simple model (Fig. 6). The discussion will deal only with the above ground fractions, as in fact the below-ground biomass is determined but not the root production or the release of root litter. The above-ground yearly production (P), the litterfall (L) and the decomposition rate (k) are of principal interest in discussing the organic matter. The content of mineral elements of the produced material (P), of the biomass increase (ΔB), of the yearly litterfall (L), of the surface litter (SL), of the canopy leached fraction (C = the difference between total throughfall and incident rainfall, see Nihlgård 1970 a) and of the incident rainfall (R) are of interest in understanding the mineral cycling.

The production (P) has already been treated. Estimating the increase of the above-ground biomass (ΔB), the whole stem wood and stem bark production values were included. From the total branch production was drawn the branch fractions of the litterfall and the rest was added to (ΔB). In the spruce forest also the needles of the yearly produced current twigs, minus the needles of the litterfall, should be included in (ΔB), but the production of needles was about 2.6 ton/ha and the needle litterfall 4.4 ton/ha/year. This difference is probably explained as the result of an earlier high production of current twigs with needles, caused by a thinning of the stand during 1961. During 1967-69 the spruce forest canopy was almost closed and a decreased current twig production was assumable, while the litterfall, originating from needles produced 4-6 years ago was still high.

The tree litterfall (Tables 6, 7) was followed during three years. Average values from these years showed about equal litterfall in the two stands, 5.7 ton/ha/year. The litterfall of the beech forest mainly came as leaves during September - October. Another peak (Fig. 7) was observable during spring, and then the main part consisted of bud scales and flowers. In the spruce forest the litterfall was more evenly spread during the year, but always showed a minimum value during the summer (July - August). Storms were of importance for the litterfall of the spruce forest. Compared with earlier reported litterfall of spruce and beech forests (see the survey of Bray & Gorham 1964), the litter figures of Kongalund are among the highest.

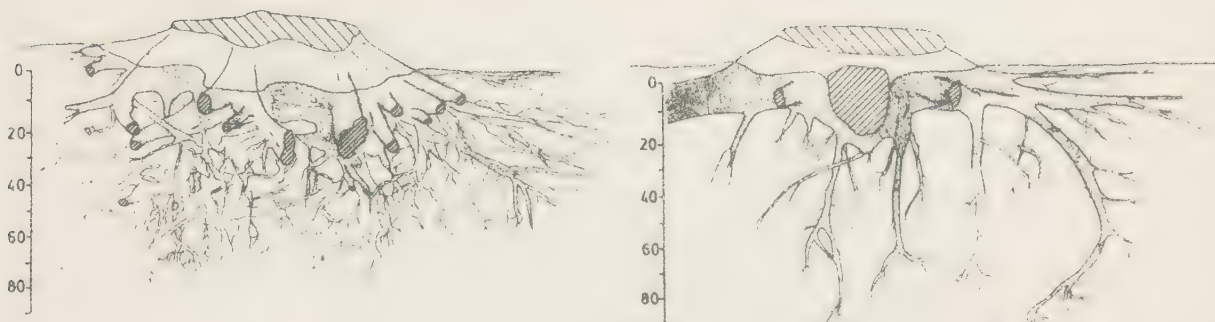


Fig.5 . The morphological appearance of the beech stump and roots (to the left) and the spruce stump and roots (to the right). Drawn from photos .

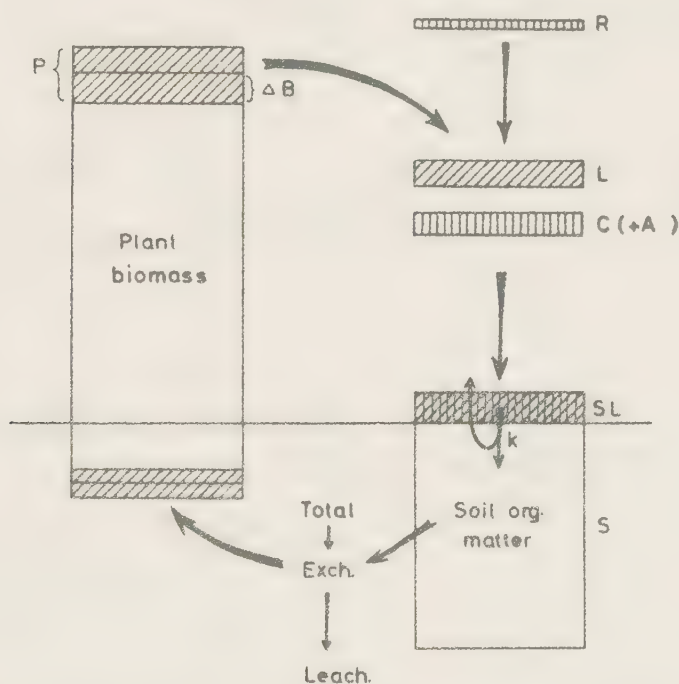


Fig.6 . A schematic model for the discussed turnover of organic matter and mineral cycling.

- B = Yearly increase of the above-ground biomass
- P = Yearly above-ground production
- R = Yearly input by rain
- L = Yearly litterfall
- C = Yearly canopy leached fraction, including A = aerosol input
- SL = Surface litter
- S = Soil organic matter
- k = Decomposition or transformation factor (L/SL)
- Total = Total amount of mineral elements in the soil
- Exch. = Exchangeable mineral elements in the soil
- Leach. = Leached mineral elements in the soil

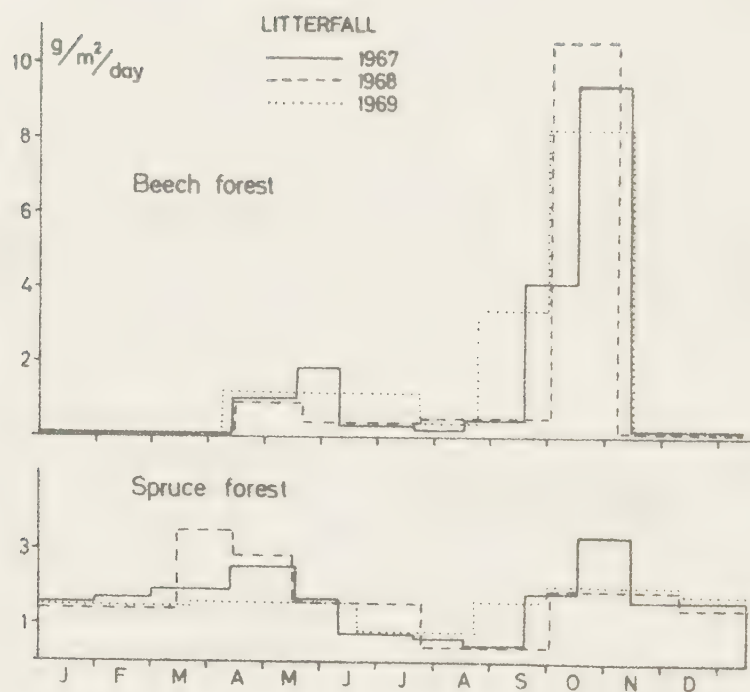


Fig.7 . The litterfall during three years (1967-1968), expressed as $\text{g/m}^2/\text{day}$.

Table 7. Distribution of chemical elements in some important functional fractions of the beech and spruce forest ecosystems.

Symbol	FRACTION	Weight ton/ha	C ton/ha	N ton/ha	C/N ratio	Si	Na	K	Ca	Mg kg/ha	Fe	Mn	S	P
BEECH FOREST														
P	Yearly	15.1	7.57	0.204	37	2.36	2.91	43.2	49.2	10.9	1.34	11.6	7.4	10.5
ΔP	" biomass increase	10.1	5.01	0.083	60	0.83	1.09	15.6	24.8	3.4	0.62	4.2	2.5	3.5
L	" litterfall	5.7	3.00	0.069	42	3.70	2.20	14.4	31.7	4.3	1.40	7.8	6.4	5.0
C	Canopy leached fraction	-	-	<0.001	-	-	10.10	11.2	6.6	2.5	0.10	2.1	10.6	<0.1
SL	Surface litter (July-67)	5.2	2.7	0.086	31	4.40	1.20	10.4	34.2	4.8	3.60	9.1	7.7	5.8
S	Soil organic matter	207	102	7.80	13	-	-	-	-	-	-	-	-	-
Exch.	Exchangeable in soil	-	-	insign.	-	-	39	56	175	35	14	10	420	84
SPRUCE FOREST														
P-ΔB	L + C	5.0	2.56	0.121	-	1.53	1.32	26.7	24.5	7.5	0.72	7.4	4.9	7.0
L + C		5.7	3.00	0.069	-	3.70	12.30	25.6	38.3	6.8	1.50	9.9	17.0	5.1
L/SL		1.10	1.11	0.80	-	0.58	1.83	1.33	0.93	0.90	0.39	0.86	0.83	0.86
SPRUCE FOREST														
P	Yearly	13.3	6.81	0.067	102	0.59	1.49	43.0	12.7	4.3	0.69	5.2	6.0	9.1
ΔB	" biomass increase	9.9	4.86	0.014	347	0.46	1.03	8.5	12.0	1.9	0.35	3.3	2.9	1.6
L	" litterfall	5.6	2.70	0.058	47	7.00	2.00	10.7	19.8	3.1	4.50	7.0	5.4	4.8
C	Canopy leached fraction	-	-	0.016	-	-	20.60	25.2	13.9	5.2	0.70	4.5	46.3	0.4
SL	Surface litter (July-67)	18.5	9.10	0.245	37	39.00	4.10	15.0	47.9	7.5	29.40	10.7	25.1	15.4
S	Soil organic matter	207	103	6.90	15	-	-	-	-	-	-	-	-	-
Exch.	Exchangeable in soil	-	-	insign.	-	-	38	65	150	31	16	14	764	146
SPRUCE FOREST														
P-ΔB	L + C	3.9	1.95	0.053	-	0.13	0.46	34.5	0.7	0.9	0.34	2.6	3.1	7.5
L + C		5.6	2.70	0.074	-	7.00	22.60	35.9	33.7	8.3	5.20	11.5	51.7	5.2
L/SL		0.30	0.30	0.24	-	0.18	0.49	0.71	0.41	0.41	0.15	0.65	0.22	0.31

Theoretically the following relation should be valid for the organic matter above ground: $(P) - (\Delta B) = (L)$. In the mineral cycling relation also the canopy leached minerals (C) must be considered: $(P) - (\Delta B) = (L) + (C)$. In Table 7 comparisons can be made, and it is seen that usually these relations do not exist. In the spruce forest the high litterfall (L) compared with (P) is obvious and has already been explained. There are several explanations why the simple relation does not hold for most elements:

1. There is a mineral change with age in the plant material. This explains especially the high content of Si, Ca, Fe and Mn in the litter but not in the newly produced material.
2. The element is easily leached and also easily taken up, i.e. it has a high circulation rate within the ecosystem. Then it always has a low concentration value in the plant material, but gives the leached canopy fraction a high figure. S could possibly be explained in this way.
3. The element is brought into the ecosystem as aerosols, and is then included in the canopy leached fraction (cf. Nihlgård 1970 a). This is certainly the main source which explain e.g. the high Na-content of the canopy leached fraction. Probably also Ca and Mg partly can be explained in this way.
4. A last reason is the uncertainty of the figures. It must be emphasized that both (P) and (ΔB)-figures are rough estimations and that (C) is an extrapolated figure.

K and P are the only elements that approximately follow the expected relation in both forest stands and moreover Mg in the beech forest, but also behind these figures certainly a more complicated relation is hidden. As mentioned above K, P, Mg and N are known to decrease with age in the plant material. Moreover micro-litter (<0.5 mm) is overlooked in this investigation, and its concentration of minerals may be high. In fact the circulation of elements within a forest may be of a polycyclic nature (cf. Ovington, 1965 p. 321).

The litter lying on the ground (SL) is exposed for leaching processes. It is also actively decomposed by microorganisms and slowly transformed into a decomposition (A_{O1}) horizon and a mull (A_1) horizon in the beech forest soil, and a mor (A_0)

horizon in the spruce forest soil (Nihlgård 1970 b). Dividing the yearly litterfall (L) by the surface litter (SL) gives decomposition or transformation factors of both the organic matter and its elements (Table 7). A high factor indicates a rapid decomposition and vice versa.

The factors of the spruce forest were pervadingly lower than those of the beech forest; in the latter the decomposition of the organic matter and the transformation of most elements seemed to be fulfilled in a year. What concerns the rapidity in transformation of the different elements, the trend was nearly the same in both stands. Thus Fe and Si had the lowest factors, i.e. the longest duration time in the surface litter. S, N and P had lower factor values than Mg and Ca, and Na, K had the highest. Relative differences were observed for Mn, which was comparable with K in the spruce forest, i.e. it had a short duration time, but in the beech forest it was comparable with P, indicating a longer duration time. This can easily be explained by the ground flora, the litter of which is included in (SL) but not in (L). Mn showed very high concentrations in the ground flora, and e.g. *Anemone nemorosa* must have contributed with Mn-rich litter in the (SL)-fraction of the beech forest, sampled in July.

To some extent the low values of the spruce forest may be explained by the continuous adding of new litter unlike the beech forest (Fig. 7), but the main reason is the accumulation of surface litter.

The below-ground functional phenomena are almost impossible to discuss. It can only be stated that the low nitrogen content of the spruce forest fractions lowered the C/N-ratio compared with the beech forest also in the soil. Moreover the increase of S and Mn and the decrease of Ca and Mg in the organic matter of the spruce forest compared with the beech forest was reflected in the exchangeable amounts of the soil.

7. Conclusions

These comparisons of biomass, productivity and element distribution between the beech and the planted spruce forest, cannot possibly be used to draw any but relative or very general conclusions on the changes that appear when a beech forest is replaced by planted spruce trees. Biomass and production du-

ring a short period are influenced by the age of the stand and by thinning procedures. As earlier was indicated the litterfall may vary depending on thinning, and it cannot be excluded that also the element distribution is affected by thinning. At the actual studied period the two stands showed about equal biomasses, which may give better possibilities of comparison.

Thus at equal biomasses the two stands also showed about equal production, 4.5 - 4.7 % of the biomass/year. The distribution on different fractions was on the other hand unlike, and the spruce production was concentrated on the stem wood but that of the beech forest on a high branch-production. The wood of the spruce stems showed low volume-weights and consequently the volume production of the spruce forest stems was considerable higher than that of the beech forest. The higher percentage of surface litter in the spruce forest was a significant difference in the organic matter distribution within the ecosystems. Further the water distribution was different in the spruce forest ecosystem, and so was the mineral distribution. Related changes were observable in the living organic fractions and in e.g. the exchangeable amounts of nutrients in the soil. The lower content of some elements of the spruce forest ecosystem can be explained in several ways, but the most credible is that spruce trees have a low request for e.g. Ca and Mg. These elements are those that have decreased most, and during a 60-year period they may have been leached and replaced for example by hydrogen ions in the soil solution. What concerns nitrogen, either a low request or a low ability to use the nitrogen in the soil could explain the decrease in the spruce forest. The opposite discussion must be brought on S and Mn which in fact have increased in the organic matter of the spruce forest.

It is obvious that spruce trees planted on former beech forest soil are able to change the soil conditions in a way that is determined by the root uptake of nutrients and water, and by the litter and its decomposition. It is impossible to know whether these changes are still going on or if a balance is achieved. Generally it must be logical to think that soil changing processes will proceed as long as the input of organic matter in the form of litter from above, differ in its chemical reactions from the soil.

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VII a. SUMMARY IN ENGLISH

The increasing area of planted spruce forests in south Sweden was the motive for this description of vegetational and ecological changes, especially when spruce have replaced beech forests in Scania.

In the first paper is shown that it is possible to divide the light dependent development of vegetation in planted spruce forests into four stages: 1. The depletion stage (0-15 years of age of the stand), 2. The bare ground stage (15-30 years of age), 3. The immigration stage (30-60 years of age) and 4. The mature stage (>60 years of age).

Five different vegetation types are distinguished: I. Moss types, II. *Deschampsia flexuosa*-types, III. *Deschampsia flexuosa*-*Oxalis acetosella*-types, IV. *Rubus idaeus* - *Oxalis acetosella*-types, V. *Sambucus* spp. - *Oxalis acetosella*-types.

The first two types are shown to appear during environmental conditions different from the others, especially concerning mechanical composition of the soil, water content and pH. Moreover the productivity was low of these two vegetation types.

The vegetation of planted spruce forests was different from that of beech forests situated by side. A change into a flora of less demanding species was observable; so called "rich" species were depleted in the spruce forests.

The microclimate was shown to differ between a beech and a planted spruce forest in Kongalund. The climate in the beech forest was variable with great differences between the leafed summer period and the other seasons. The climate in the spruce forest was uniform throughout the year. The primary site factor causing differences between beech and spruce forests is probably incoming radiation, which influences both the temperature and the relative humidity. All differences were greatest in the spring, while in the summer the conditions seemed to be the same, although there were slightly

lower soil temperatures in the spruce forest. Also during late autumn when the beech trees have dropped their leaves the climate differences were small, due to the low incoming radiation. The light was considered as the primary cause for the development of the spring flora in the beech forest and as a limiting site factor for the ground vegetation in the spruce forest.

The distribution and the chemical composition of the rainfall reaching the ground, differs greatly between the beech and spruce forest in Kongalund. 20 % less rainwater reaches the ground in the spruce forest, but it contains about double as much of different nutrients as that of the beech forest, probably owing to the leaching of dying or dead needles still on the branches. A high percentage of the elements in the rainfall must derive from dry deposited aerosols and this is particularly so for Na, Mg, Cl and Ca.

The soil of the spruce forest is about 19 % drier during the whole year than the soil of the beech forest, and less rainwater is transported to the underground water in the spruce forest. This is explained by the high interception, by a long transpiration period and by a redistribution of water inside the spruce forest ecosystem, in the way that the biomass fractions of the spruce forest contains more water than those of the beech forest.

Other soil differences between beech and side by side situated planted spruce forests are podsolizing characters of the spruce forest soil; the development of mor and leached horizons. pH decreases, a decrease of nitrogen and of exchangeable amounts of K and Ca and an increase of Mn, Fe, SO_4 and PO_4 are observable in the spruce forest soil.

In the Kongalund stands related changes are found in the chemical composition of the biomass and the exchangeable amounts of the soil. The beech and spruce forest investigated in Kongalund, show about equal biomass and production, but the distribution on different fractions is unequal. E.g. the stem production constitutes only 28 % of the total in the beech forest but 57 % in the spruce forest. On a volume

basis the difference is still higher. In a discussion on the biogeochemical circulation the relation $P - \Delta B = L + C$ is set up. P is the yearly production, ΔB the yearly increase in biomass, L is the yearly litterfall and C the yearly canopy leached fraction. The deviations from this relation are explained as mineral changes with age in the plant material, as a transport to the ecosystem of aerosols included in C and as a high circulation rate of the element inside the ecosystem.

VII b. SUMMARY IN SWEDISH

Sammanfattning

En ökande areal av planterad granskog i Skåne har initierat denna undersökning över förändringar, avseende dels vegetationen dels ekologiska parametrar, som kan iakttagas då planterad gran ersatt bokskog.

I ett första avsnitt beskrives den allmänna utvecklingen av vegetation i planterade granbestånd, samt vilka vegetations typer som kan urskiljas. Jämförelser göres med bokskogsvegetationen i parvis belägna provytor.

Vegetationsutvecklingen i planterade granskogar är avhängig av främst ljustillgången, vilket indirekt avspeglas i vegetationstäckningens korrelation med trädtäthet, krontäckning och trädålder. Man kan i princip urskilja fyra olika vegetationsstadier under granskogens omloppstid: 1. "Utsläckningsstadiet", varande ifrån planteringsstadiet till dess att vegetationen försvunnit p.g.a. ljusbrist. 2. Kala markstadiet, vid en beståndsålder på 15-30 år då ingen fanerogam vegetation, utan endast enstaka exemplar av t.ex. *Lophocolea heterophylla*, *Plagiothecium* spp. kan hittas. 3. Invandringsstadiet då mindre ljuskrävande arter, t.ex. *Oxalis acetosella* börjar finnas i utgallringsöppningar. Stadiet varar upp till en beståndsålder på ca 60 år. Därefter kommer 4. Moget stadium, under vilket marken till större delen täckes av vegetation. Detta är vanligen fallet vid en trädtäthet på 5-8 träd/100 m² och vid en krontäckning på 70-80 %.

Fem huvudtyper av vegetation urskiljes på grundval av dominansförhållanden. I den på näringsfattig urbergsmorän eller sand förekommande första typen (I) dominerar olika mossor som *Dicranum majus*, *D. scoparium*, *D. undulatum*, *Hypnum cupressiforme*, *Plagiothecium* spp., *Pleurozium schreberi*, Typ II domineras av *Deschampsia flexuosa*, ofta tillsammans med ett antal torrtoleranta mossor, och förekommer på torr urbergsmorän. På i markytan och kubikmetertillväxten/år av det nuvarande beståndet är lägre i dessa två första typer jämfört med de tre följande.

Typ III-V visar ofta ett inslag av finkorniga jordarter mo, mjäla och ler, till skillnad från I och II. Den tredje vegetationstypen, Deschampsia - Oxalis typen, kännetecknas av ett markant inslag av Oxalis acetosella, ovanpå vilken Deschampsia flexuosa har brett ut sig i takt med ökat ljusinsläpp. På något fuktigare marker tillkommer en kraftig ormbunksvegetation, med bl.a. Dryopteris austriaca. Vid tillräckligt ljusinsläpp uppträder buskar av Sorbus aucuparia och Sambucus racemosa.

Den fjärde typen är en Rubus-Oxalis typ (IV), i vilken nedbrytningsförhållandena är goda och ett mellanting mellan mår och mull har utbildats. Rubus idaeus kan utvecklas i ett heltäckande skikt även i relativt slutna granbestånd. Liksom i typerna III och V kan dock Oxalis acetosella anses vara den ört som först koloniserar marken, varefter vid ökat ljusinträde Rubus idaeus kommer in. I en speciell variant på starkt kalkrikt underlag och med pH i markytan över 6, bildas en fin mull och arter som Lamium galeobdolon, Mercurialis perennis, Campanula latifolia och Actea spicata inträder.

Sambucus-Oxalis typen (V) domineras till minst 50 % av Sambucus racemosa eller S. nigra i buskskiktet. Denna typ utbildas gärna på lerjordar med ett högt vattenstånd. Humustypen är ett mellanting mellan mull och mår och nedbrytningshastigheten tycks vara hög. Från försöksytor tillhörande Skogsforskningsinstitutet framgick att en Deschampsia-Oxalis-vegetationstyp med mår, efter kraftig kalkning omvandlas till en Sambucus-Oxalis-typ med mull och med ett flertal rikindikerande arter. En steril variant av Sambucus-Oxalis-typen påträffas i granskogar planterade på gamla åkermarker, belägna långt ifrån skogsbygd och ur spridningssynpunkt isolerade. Här finns nästan enbart Sambucus-buskar samt oftast Moehringia trinervia, och ett tjockt barrlager täcker markytan.

Av parvis belägna provytor med bok- och granskog framgick att vegetationens artsammansättning förändras i riktning mot vad som allmänt betraktas som fattigare. Typiska ängsskogsväxter försvann eller minskade starkt i täckningsgrad och frekvens i granskogarna. Stellaria nemorum ssp. glochidosperma, känd som en surtolerant art, klarade sig av dessa bäst.

I följande avsnitt behandlas främst undersökningar från Kongalund söder om Söderåsen i Skåne, där ett bokskogs- och ett planterat granskogsekosystem har analyserats. Först behandlas mikroklimatiska olikheter mellan ekosystemen.

Av tre klimatdygnsresultat framgår att under vårperioden ca 35 % av totalt ljusinflöde når marken i bokskogen och höjer marktemperaturen betydligt mera än i granskogen där endast 2-3 % av solljuset når marken. Under sommaren är förhållandena i stort sett lika vad gäller ljusinflödet, men en aktiv tillväxt i fältskiktet kan observeras enbart i bokskogen. I granskogen saknas fältskiktsvegetation och slutsatsen dras att för fältskiktets utveckling inte enbart vårsolens gynnsamma inflytande i bokskogen är av betydelse, utan även bättre markförhållanden, t.ex. fuktighet och surhetsgrad i bokskogens mull jämfört med granskogens mår. Under senhösten är det totala ljusinflödet mycket litet, men förhållandet mellan bokskogen och granskogen är ungefär detsamma som under vårperioden.

En grov omräkning till $\text{cal/cm}^2/\text{år}$ ger vid handen att ca fyra gånger så mycket energi kommer till bokskogsmarken som till granskogsmarken, en skillnad som främst kan hänföras till vårperioden. Ljusinflödet kan anses som den primära orsaken till våraspektens utveckling i bokskogen, och som en begränsande faktor för fältskiktets utveckling i granskogen.

Temperaturförhållandena har förutom under dygnsförsöken följts i markytan och på 25 cm djup under året 1967-68. Veckomedeltemperaturerna var genomgående något lägre, dock utan att alltid vara signifikanta, i granskogsmarken. Under vårperioden var maximitemperaturerna betydligt högre i bokskogsmarken.

Den relativa fuktigheten var omvänt beroende av instrålningen och kan i genomsnitt under året antagas vara något högre i granskogen.

Vindhastigheten var under dygnsförsöken mycket låga.

Den nederbörd som kommer till marken skiljer sig både i kvantitet och kvalitet mellan de två bestånden. Direkt genomfallande regn, stamrinning och interception är i bokskogen 70 %, 11 % och 19 %, i granskogen 58 %, 3 % och 39 %, dvs till marken kommer ca 80 % i bokskogen, ca 60 % i granskogen av den totala nederbörden (100 %) ute på fritt fält. I sin

kemiska sammansättning skiljer sig nederbördsvattnet i granskogen från det i bokskogen framför allt genom ett betydligt lägre pH och genom mer än dubbelt så höga koncentrationer av olika ämnen. pH i nederbörden på fritt fält ligger på 5.2, det i bokskogen på 5.7 och det i granskogen på 4.5. Speciellt surt är granarnas stamrinningsvatten, med pH på 3.1. Trots 20 % lägre nederbörd kommer dubbelt så mycket näringsämnen till marken i granskogen, 215 kg/ha/år, som i bokskogen, 107 kg/ha/år. En stor del av näringsämnena härrör från vindspritt material. Bl.a. gäller detta Na, Cl, Mg och Ca, i betydligt mindre utsträckning S, P, K, Mn och N. Detta visas genom ett experiment med uppspända plastnät under vilka nederbörden analyseras. Av relativa jämförelser kan inte konstateras att t.ex. granskogen skulle vara mera aerosol-uppfångande än bokskogen. En hög koncentration av speciellt S men även N i nederbörssvattnet i granskogen, anses därför bero på urlakningsprocesser av döda eller halvdöda barr som fortfarande sitter på grenarna.

Markvattenförhållandena skiljer sig också markant mellan de två ekosystemen. Den totala markvattenhalten med till 60 cm djup, ligger i bokskogen genomgående ca 20 % (=42 mm) högre i bokskogen än i granskogen. Detta beror bl.a. på den höga interceptionen och på en lång transpirationsperiod i granskogen, men till en icke oväsentlig del också på en omfördelning av vattnet i granskogsekosystemet, så att i de organiska fraktionerna biomassa och förna finns nära dubbelt så mycket vatten (=240 ton/ha mer, motsvarande 24 mm regn) i granskogen som i bokskogen. Dessa skillnader i hydrologisk balans har bl.a. som resultat att en obetydlig mängd nederbördsvatten tillföres grundvattnet i granskogen jämfört med i bokskogen. Speciellt under vår och höst är vattenmängderna så stora i bokskogsmarken att dränerbart, dvs nedåtgående, vatten uppträder på ca 50 cm djup, vilket ej är fallet i granskogsmarken.

Övriga markförändringar som iakttages på lokaler där bokskog ersatts med planterad granskog är dels av strukturell och fysikalisk karaktär, dels av kemisk karaktär. De viktigaste är: 1. Uppbyggande av mårskikt, vilket kan anses bero på lägre temperatur, minskad nedbrytningsaktivitet, barrrens surhetsgrad och innehåll av svårnedbrytbara substanser. Ett mår-

skikt innebär högre glödförlust, ökad porositet och minskad vattenhållande förmåga jämfört med mullskiktet i bokskogen.

2. Den tidigare bokskogsmullen har försvunnit eller förändrats på de flesta jordar och det sker en utveckling mot en urlakningshorisont under mårskiktet i granskogsmarken. Den uppkomna markprofilen kan beskrivas som en podsoloid. På vissa jordar sker en tydlig utbildning även av en utfällningshorisont. 3. De kemiska förändringarna innebär bl.a. sänkt pH i granskogen med ca 0,5 enheter i markytan och 0,1 - 0,2 enheter på 50 cm djup. Samtidigt en ökad halt av utbytbara vätejoner. Utbytbara halter av framför allt K, Ca och Mg sjunker medan Fe, Mn, SO_4 , PO_4 -halterna tycks öka, troligen beroende på det sänkta pH. C/N-kvoten ökar i granskogen, beroende på en minskad kvävehalt i det organiska materialet. 4. Mobiliseringen av N visas vara beroende av temperaturen, och nitrifikationen, dvs överförandet av NH_4 till NO_3 är betydligt mindre i granskogen än i bokskogen.

De organiska fraktionerna i ekosystemen fördelar sig på biomassa, förna och markhumus. I Kongalund är växtbiomassan ungefär lika stor i granskogen som i bokskogen, 367 resp. 375 ton/ha. Den årliga produktionen av växtbiomassa är likaledes av ungefär samma storleksordning, 16,3 resp. 17,8 ton/ha/år. Fördelningen på olika komponenter är emellertid helt olika. Av biomassan utgör således stamkomponenten ca 56 % i bokskogen men 66 % i granskogen. Stamproduktionen utgör 28 % av totala produktionen i bokskogen, 57 % i granskogen. En betydligt större del av årsproduktionen ligger således i grenar och årsskott i bokskogen än i granskogen. Volymmässigt är stamproduktionen ännu större i granskogen än i bokskogen, p.g.a. granvedens låga volymvikt.

Markförnan är i bokskogen (Juli 1967) ca 5 ton/ha och i granskogen ca 19 ton/ha. Någon större skillnad i total markhumushalt (0-60 cm djup) föreligger inte men fördelningen i profilen är något förändrad så att mera organiskt material finns i markytan och mindre på djupet i granskogen jämfört med bokskogen.

Den minerogena fördelningen inom ekosystemen har förändrats, så att mindre metallämnen, med undantag av Mn, finns i biomassan i granskogen. Likaså finns mindre N, däremot mera S och i de ovanjordiska delarna även mera Si och P i granbiomassan. Motsvarande förändringar kunde märkas beträffande utbytbara halter av ämnena i marken.

I en diskussion över olika fraktioners och olika ämnens sam-

band ovan mark, användes det teoretiska förhållandet: $P - A B = L + C$, där P är produktionen ovan jord, A B den årliga biomassaökningen, L är förnandedfallet och C är urlakningen av ämnen från krontaket. Detta samband visas inte existera beträffande de flesta ämnen. Främsta orsakerna till detta är att mineralinnehållet i nyproducerat material skiljer sig ifrån äldre material, dvs det sker successiva ändringar så att vissa ämnen ökar med åldern, t.ex. Si, Ca, Fe, Mn, medan andra ämnen minskar t.ex. K, P, Mg, N. En annan orsak är att urlakning eller exkretion samt snabb återupptagning via rötterna ger ämnet en hög koncentration i kronurlakningsfraktionen C, men en låg koncentration i växtmaterialet, dvs det föreligger en snabb cirkulationshastighet inom ekosystemet för ämnet ifråga. En tredje orsak, och troligen den viktigaste, är tillförseln av aerosoler, vilka sätter sig i kronan, tvättas ned och inräknas i fraktionen C. Detta gäller speciellt Na, men förvisso också Ca och Mg.

Förhållandet mellan förnafallet L och markförnan SL, visar att omsättningen av förnan och dess ämnen är betydligt snabbare i bokskogen än i granskogen. I bokskogen tycks den årliga tillförseln av förna motsvaras av en lika stor nedbrytning. Fe och Si visade sig ha den längsta uppehållstiden i förnan, därefter kom S, N, P med längre uppehållstid än Ca och Mg och slutligen Na, K med snabbaste omsättningshastighet.

Sammanfattningsvis kan sägas att i ett planterat granskogsekosystem vegetation och mark påverkas på ett helt annat sätt än i ett bokskogsekosystem. De organiska fraktionerna och vattnet fördelar sig olika. Den totala produktionen tycks viktsmässigt inte öka, däremot volymmässigt. Ur biogeokemisk synpunkt påverkas marken så att vissa ämnesfraktioner ökar, andra minskar, beroende på rötternas upptagning av näringsämnen och vatten samt förnans sammansättning och nedbrytning.

